BRAIN.

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GUNSHOT WOUNDS OF THE SCALP, WITH SPECIAL REFERENCE TO THE NEUROLOGICAL SIGNS PRESENTED.

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IT is common knowledge that, owing to the resilience of the cranial vault, it is possible for a severe blow to cause an injury of the underlying brain without an actual fracture of the calvarium occurring. It is granted that this injury may be sufficiently severe to manifest itself by definite and unequivocal clinical signs, but it is not sufficiently well known how common such cerebral contusion is. A scalp wound is usually regarded as a trivial thing with an unusually happy prognosis

as regards healing, even when grossly infected. Attention has, however, been too sharply focused upon the wound of the soft parts, to the exclusion of the deeper lesion so often present and so vastly more important than the other. No class of head injury better illustrates the aphorism of Hippocrates with which Percival Pott prefaces his work on the nature and consequence of wounds and contusions of the head—"Nullum capitis vulnus contemnendum." The object of the present paper is to attempt to rescue scalp wounds from the position of

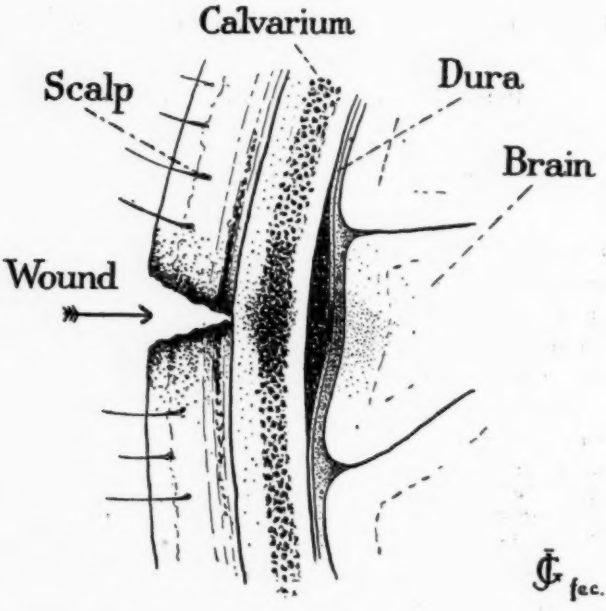

FIG. 1.—Scheme of scalp wound with intracranial injury, the calvarium being intact. Bruising of bone and dura, with small extradural and cortico-meningeal hæmorrhage.

contempt which they too often occupy. It is true that the brain injury is rarely of a very serious character unless the calvarium has given way and so allowed the force to continue and to act unopposedly on the hemisphere, but deaths from scalp wounds do sometimes occur. The lesser grades of brain injury are by no means the least interesting, and below will be found evidences of injury of very varying degrees of severity.

Two factors have undoubtedly contributed to the failure to recognize intracranial upset in head injuries. In the first place the disturbance is often very slight, and in the second it wears off comparatively rapidly, frequently within a week, so that unless a neurological examination is made at once signs will be missed, and by the time these patients reach the United Kingdom all objective signs have passed away. A third factor may be added, and it is this, that the great pressure of work in France has caused most of us to confine our attention to cases more insistent in their claims, such as the penetrating wounds of the head. But that the closer investigation of scalp wounds amounts to more than a luxury, the histories set forth below will show.

The only recent references to contusion in scalp wounds are those of Adie and Wagstaffe [1] and of Harvey Cushing [2]. The former note three Jacksonian fits in 118 cases and one death (from pneumonia), the latter one death from hæmorrhage into the vermis and cerebellar fossa. Cushing, however, makes the following remark: "It is quite possible that some of the other cases in this group [scalp wounds] should not only have been trephined but should have had the dura opened as well, for eleven out of the number [i.e., 50 per cent.] showed distinct evidence of moderate intracranial damage."

In the series now to be brought forward, no less than seventeen out of fifty-four showed evidence of local contusion, and all but five a cerebral disturbance of some sort or other.

II.—Material.

The observations embodied in this paper are based upon a series of fifty-four scalp wounds under my care in the Head Service of 14 General Hospital between the months of July and November, 1918. The number of cases is admittedly very small, but they are quite unselected, some slight, some severe, and are typical of the average run of scalp wounds as seen at the base in France. A few had been operated upon before admission, but the majority were untouched. It was a general rule which admitted of no exception that all head wounds, however trivial they might appear to be, should be submitted to a rough neurological examination before operation. These remarks are the result of observations so made, often very sketchy, and jotted down under extreme pressure of work.

There can be no question but that head wounds of all degrees of severity benefit from collection into one place, where they can be kept

for a long time before being moved further, and where they can receive the benefits of standardization and continuity of treatment.

III.—The Trauma.

The protective value of the steel helmet is undoubtedly great, but beneath its shelter a man may receive a blow of very considerable severity without fracture of the calvarium. This is corroborated by those cases, and several were noted, where the helmet has been deeply indented without being perforated and the patient has suffered a considerable scalp wound with underlying cerebral contusion. But for the helmet, the shell fragment would undoubtedly have penetrated the head, and the case have thus passed into a graver category.

How severe the blow on the head may be is illustrated by a man who remarked several days after he had been wounded that he "could hear the old tin hat ringing still." In one or two cases the fragment has hit the helmet with such force as to break the chin-strap. This is liable to occur with bullet wounds whose trajectory is flat, whilst shrapnel bursting above tends to drive the helmet on to the head.

Notes were kept on the nature of the injury to the steel helmet as far as could be determined. Reliance had usually to be placed on the man's own statement, as not many patients succeed in getting their helmets through to the base. In conjunction with the position and extent of the scalp wound, the injury to the "tin hat" helps one to form a clearer mental picture of the exact nature of the force which has been applied, and, in my opinion, the helmets should always have accompanied the patients on their journey right through to England.

IV.—Character of the Scalp Wounds.

The wounds of the scalp were of the usual type, with contused ragged edges. They varied from one-half to four inches in length, and were from one to two days old on admission. Owing to the vascularity of the scalp, they did well with conservative excision and suture with a rubber tissue drain. The wound extended almost invariably to the pericranium, and when this was torn it was not uncommon to see a faint bruise in the bone like a shadow beneath the external table. In none of the series now under consideration was there a fracture of outer or inner table.

V.—Type of Operation performed.

Of the operative methods used little need be said here. Excision of the scalp wound as sparingly as was compatible with removal of all hopelessly contused and infected tissue was performed. The wound was then washed over with flavine followed by warm saline to remove the albuminate first formed, and then rinsed with flavine again. Catgut sutures were inserted in the galea, and the wound closed with interrupted silkworm-gut sutures, twisted twice but not knotted. A trephine disc was removed three times (see below). The anæsthetic of choice is undoubtedly novocain—adrenalin, with a hypodermic injection of omnopon $\frac{2}{3}$ gr., and scopolamine $\frac{1}{100}$ gr. an hour beforehand. The advantages are: a minimal loss of blood (and such loss may assume formidable proportions if plastic flaps have to be cut), and, secondly, the great comfort of having a conscious patient who can lie in the position most convenient to the surgeon unembarrassed by an anæsthetist. This is of especial value in wounds of the posterior part of the head. A great part of the art of surgery lies in making things easy for yourself (to paraphrase a remark of Charles Mayo's), and local anæsthesia makes this possible for the head in a way which must be surprising to any one not already conversant with its convenience.

The dura was not incised at operation either in this or in the depressed fracture series, as sepsis was already established, and it did not seem justifiable to incur the added risk which this step would have entailed. It may be noted that none seemed to be the worse for this conservatism.

VI.—Concussional Changes.

A large number of the cases showed generalized signs; a history of unconsciousness, complete or partial, with vomiting, nausea, headache, and exaggeration of the tendon jerks generally, so that one must define some standard for the diagnosis of contusion apart and aside from such signs. In the Rolandic lesions such signs can be traced through all grades of severity from a local increase of the tendon jerks and a few beats of ankle clonus on the side opposite the lesion, these being absent on the same side, up through slight aphasias, numbnesses and pareses, finally culminating in definite palsies and Jacksonian fits. In no type of cases can the effects of cerebral contusion in its varying gradations of severity be more beautifully traced.

It will be readily acknowledged that signs of contusion of the silent

areas of the brain, particularly of the frontal lobes, are very difficult to detect. It is not until the wound falls over a non-silent area, such as the motor or visual cortex, that one is able to say with accuracy whether or not the impact of the missile has caused a local lesion. These localizing signs have to be distinguished from the concussional and post-concussional effects which are met with in severe cranial injuries whatever their site.

VII.—General Signs.

The signs of intracranial disturbance common to all, whether concussional cases or locally contused cases, will be now discussed with a view to determining their frequence. Those cases in which a localized cerebral injury has occurred will then be dealt with.

It may be stated at once that only five patients out of the whole series showed no positive neurological signs at all. In ten more the only thing complained of was headache, but this was often so severe and the patients were mentally so dull for a short time that one could not doubt that the brain had received a severe shaking up. All the other cases presented additional and unmistakable signs which made the diagnosis sure.

Unconsciousness.—As regards a period of unconsciousness, one can here only rely on the man's statement, as it was always of short duration, and was gone by the time he reached a Casualty Clearing Station. To the patient, the border line between being stunned and being actually unconscious is indistinct. One quarter of them allege that they were actually unconscious for brief periods, whilst another quarter were stunned, frequently being knocked down by the impact of the missile.

Headache.—As might have been expected, headache has been more commonly present than any other symptom. Out of the fifty-four cases it was present in forty-five, definitely absent in six, and not noted in three. A note was kept as to its situation with a view to determining, if possible, some connexion between the site of the wound and that of the headache. It was "fixed," severest in the region underlying the wound, in twenty-three cases, roughly 45 per cent. As it improves, it tends to become frontal, and this was the commonest general site for headache. Frontal headache was present with wounds of the vertex, temporal, parietal and occipital regions indiscriminately.

When it occurs in occipital wounds it is difficult to be certain that it is not the result of a local trauma by *contrecoup*, and occipital and frontal headache were sometimes associated. One can only conclude that it is due to a general upset of the intracranial circulation or localized œdema the result of the trauma. It was most severe in the evening just when settling down for the night, and often appeared then when it had been absent throughout the day.

Giddiness was the next commonest sign, only being noted on gross changes of posture, and therefore later in convalescence when such active movements began to be attempted. It was never a serious factor.

Nausea and vomiting.—These two valuable positive signs of severe intracranial disturbance were, as might be expected, not frequently presented by this series of scalp wounds. Vomiting occurred in eight cases and nausea was, or had been, present in thirteen.

Tendon jerks were exaggerated in twenty cases in all, and of these eight presented increase of both arm and leg jerks. Increase of the arm jerks always portended a graver injury, and cerebral injury was always suspected when they were active.

Clonus.—True ankle and patellar clonus, continuous and regular, was never found, but a few beats, from two or three to six, occurred in seven cases. But when present on one side only, even this mild form has a value.

One or other of these general signs was present in the vast majority of the cases of this series and were the result of the force which inflicted the wound. To a certain extent their significance was merely concussional and due to the impact of the missile on the steel helmet which tended to distribute the force generally all over the head.

All cases from the Head Service were given M.R.C. form 6 and a slip as well asking them to communicate with me at the end of a month or on discharge to an auxiliary hospital. Judging from their answers it seems that a large hysterical element often developed, and many complained later of headache and sleeplessness, and weakness in limbs which had appeared to be entirely recovered before they were sent across the Channel. This is not to say that they were malingering but that they had acquired a true hysteria (see, for instance, Cases 8 and 11).

The three following records are illustrative of varying grades of concussional injuries:—

Cases 1 *and* 2.—*Scalp wounds presenting evidence of slight general intracranial upset of a concussional type.*

Private J. C. (Series No. 24). Shell wound over right parietal bone, August 27, 1918. Wound overlies Rolando. Steel helmet worn, one hole in it. Admitted No. 14 General Hospital August 28, 1918. Dirty contused wound. Never unconscious, no vomiting. Nausea ++, yesterday. Headache +, frontal. Tendon reflexes: arms normal, legs exaggerated, equal. Plantar reflex, flexor. No palsies. Mentally quite clear.

August 28, 1918.—Operation, novocain-adrenalin anæsthesia, wound completely excised, bone bare over an area 1·0 cm. diameter, uninjured. Suture with flavine gauze wick.

August 30, 1918.—Wick removed.

September 5, 1918.—Evacuated to United Kingdom, condition excellent.

Private P. J. (Series No. 48). Bullet wound over right parietal bone September 9, 1918; excised in — Casualty Clearing Station next day, no bone injury. Admitted No. 14 General Hospital September 12, 1918. Steel helmet presented one hole and a groove on the inner surface. The bullet evidently followed the curve of the helmet and escaped between the head and the brim. Never unconscious, no vomiting. Nausea +, slight, when first hit. Headache +, fixed, not severe. Tendon reflexes all normal. Plantar reflex flexor. Palsies nil. Pulse 72.

September 20, 1918. — No headache, no neurological abnormalities. Evacuated to United Kingdom.

Case 3 (*Series No.* 69).—*Scalp wound of vertex presenting severe concussional signs.*

Sergeant W. H. H. Shell wound extending from mid-line, 3½ in. to the left transversely, 2 in. in front of Rolando above, October 31, 1918. Dressed in — Casualty Clearing Station (no notes from there). Admitted No. 14 General Hospital November 7, 1918, a week after being wounded. Patient stated that he was semiconscious for about two days in the Casualty Clearing Station, remembers being very restless. Headache ++, both temples. Says he vomited many times at first. No nausea now, clear mentally. Tendon reflexes, arms +, legs ++, equal. Ankle clonus, 6 beats both sides. Plantar reflex flexor. No palsies. X-ray, no fracture detected.

November 8, 1918. Operation, novocain-adrenalin anæsthesia, wound excised, bone had been bared in centre of wound. Wiped out with bismuth, iodoform, paraffin paste suture.

November 15, 1918. Doing well, headache, slight frontal at night.

November 18, 1918. No headache, tendon reflexes normal. Evacuated, United Kingdom.

Such, then, are the neurological findings in about 50 per cent. of scalp wounds, denoting an intracranial upset of more or less severity, but of a generalized nature. There were no definite signs of a localizing

character by which one could say that one limited area of the brain had suffered more severely than another. We must now turn to those cases in which definite signs were present to such a degree that one is justified in saying that such and such an area had suffered a local contusion. We shall see, in fact, the special signs of a local contusion lifting their heads above the general ruck of signs of the coincident concussional changes.

VIII.—Cerebral Contusion in Scalp Wounds.

As has been remarked, local contusion was detected in seventeen cases of the fifty-four of this series, that is, 31·5 per cent. In thirteen the lesion was Rolandic, and in two of these there was an added sensory disorder, whilst in four the lesion was occipital with visual disturbance. It is notoriously exceedingly difficult to determine whether there has been a contusion when one is dealing with the silent areas. Visual and motor lesions are comparatively easy to recognize, but it is a different matter with the frontal lobes and some parts of the temporal and occipital areas. That contusions of the silent areas did occur, but were undetected, there can be little doubt. So that the figures given are probably too low, as they deal only with the motor and visual areas, and to a certain extent with the parietal area too. This leaves a large part of the hemispheres unaccounted for. Head's work on the sensory cortex was unpublished at the time that these observations were made, and if his discriminatory tests had been applied, no doubt some interesting facts would have been obtained. In forming a true estimate, therefore, of the frequency of cerebral contusion beneath an intact skull, one can arrive at an approximately accurate conclusion only by noting the number of cases in which the injury fell over a non-silent area, and comparing this figure with that of the number which showed a definite contusion.

The results of this analysis are as follows: of the fifty-four cases thirty-nine overlay non-silent areas, and of these seventeen showed signs of cerebral contusion. This gives a percentage of 43·6, in place of the 31·5 just noted. These figures are high, but I, personally, am inclined to believe in the higher rather than the lower. The number of cases is too small for dogmatic statements to be based on them, and it remains for future investigations on larger numbers to correct or corroborate them. It is unlikely that the accidental scalp wounds of civil practice will show anything like so high a percentage of brain injury, for the force expended in producing them cannot compare with that of the high

velocity projectile which has generally pierced a steel helmet before inflicting the wound.

To turn now to a more detailed examination of the various contusions.

(*a*) *Contusions of the Motor Cortex* (*Thirteen Cases*).

Contusion of the motor cortex evidenced itself by motor aphasias and by palsies of all grades of severity. It was usual for the paralysis to be limited to two organs—in fact, a complete hemiplegia was never seen. In some cases the injury was very slight, and a local increase of tendon reflexes was all that was noted (see the illustrative cases below). The face and arm suffered most, and the movements of the fingers more than those of the elbow and shoulder. In fact there was an often repeated syndrome of aphasia with palsy of the right face and hand for low left Rolandic lesions, the aphasia being omitted when the blow fell on the right side. In two cases the pre-operative neurological findings were so definite that I removed a bone disc, although the cranium was quite intact. In one an extradural clot was found, in the other nothing (see Cases 6 and 10). In a third case the findings were equally definite, but this step was not taken, and I had the mortification of seeing him develop Jacksonian fits, and when a decompression was done a clot was found and washed away with no return of epilepsy (see Case 7). Jacksonian seizures occurred in three cases in all—the one just mentioned and in two others, which had already been operated upon in casualty clearing stations before admission to No. 14 General Hospital. One of these latter was completely controlled by large doses of bromide (30 gr. every two hours continued for three days). In the second recourse had to be had to lumbar puncture, and after this there was no return of convulsions. The Jacksonian fits seen in some of these head wounds, not only in scalp wounds but in depressed fractures as well, though we are not at present concerned with these last, are often of a very severe and protracted nature. In Case 9 there was hardly any interval between the second and third fit, and the twitchings continued until he was anæsthetized. In Case 7 the fit lasted for thirty-five minutes. These cases call to mind the four cases presented before the Moscow Neurological Society by Kozhevnikov under the title of "A special form of cortical epilepsy," or partial continued epilepsy. By this he meant continuous twitchings, which rose into a definite convulsion and faded again into local contractions, rising again to a convulsion, and so on without ceasing. A very pretty case was

recently recorded by Pollosson and Collet [8]. In their case there was no injury to the calvarium, but they found an extradural clot on trephining. The character of the Jacksonian fits noted in my own cases seem to be stepping-stones on the way to a full-tide Kozhevnikov's syndrome.

The following six cases are illustrative of contusions of the motor cortex, and include motor aphasia and facial palsy, paralysis of face and hand (two cases), and three cases in which the hand was affected in excess of anything else. They include the three Jacksonian cases.

Case 4.—*Scalp wound over lower part of left motor cortex. Slight facial palsy and motor aphasia. Cranium intact. Recovered.*

Lance-Corporal T. C. (Series No. 35). Machine-gun bullet wound, September 1, 1918, 4 in. long, over left parietal bone, crosses Rolando low down. Steel helmet worn, two holes found in it. Scalp wound excised in — Casualty Clearing Station, no bone damage. Admitted to No. 14 General Hospital September 12, 1918. Clean healed scalp wound. Headache +, "fixed," occasional. Vomit −. Nausea + at times. Unconscious −, stunned +. Grips normal, equal. Tendon jerks +, clonus three beats right, nil left. Plantar reflex, flexor. Has slight right facial palsy, tongue tip deviates to right, with mild grade of motor aphasia. Was X-rayed in Casualty Clearing Station, report no fracture. Re-X-rayed here, no fracture detected.

October 24, 1918. Evacuated to United Kingdom, slight evening headache only.

October 16, 1918. Heard from, has severe headache, gets up, but then has acute pains in the head.

Case 5.—*Scalp wound over lower part of motor area; cranium intact. Paresis right arm. Recovered.*

Private H. T. (Series No. 38). Shell wound over left parietal, 2 in. long, October 14, 1918. Wound lies across lower end of Rolando; excised in — Casualty Clearing Station same day. Admitted No. 14 General Hospital October '17, 1918. Clean sutured wound. Vomit −, nausea + at first. Walked 200 yards to aid post after being hit. Unconscious −, stunned +. When first hit right arm became numb immediately, could not do anything with it. Legs were weak, had to be helped along. On admission hand was much better, but finger movements were clumsy; shoulder and elbow normal. Slight left facial palsy, tongue tip deviates to left. No aphasia. Tendon jerks normal. Pulse 80.

October 24, 1918. Greatly improved. Palsies recovering rapidly. Tendon jerks normal. No headache.

The next case presents an injury of the motor cortex with an associated lesion of the post-central gyrus. A better example of anæsthesia of cortical origin will be found in Case 10 (*vide infra*).

Case 6.—*Scalp wound over left motor and sensory cortex. Palsy right side of face and partial anæsthesia of hand of cortical origin. Cranium intact. Trephined; extradural clot discovered. Recovery.*

Lance-Corporal C. F. (Series No. 62). Rifle-bullet wound over left parietal bone September 3, 1918. Wound crosses middle of Rolando. Two clean holes drilled in steel helmet. Admitted No. 14 General Hospital, September 4, 1918. Was unconscious for a few seconds when hit, and about ten minutes afterwards felt numbness in right hand which then hung loosely at his side. Headache +, frontal; vomited twice in — Casualty Clearing Station. Nausea now, slight. Right hand numb, grip very weak; slight palsy right side of face. Tendon jerks, right side +, left normal. Radiograph, metal dust in scalp; no fracture.

September 4, 1918. Operation: Wound excised, no fracture found. In view of pre-operative neurological findings, a bone disc was removed and an extradural clot $1\frac{1}{2}$ in. in diameter discovered. Sponged away with hot saline, flavine wash. Dura not opened. Wound closed in layers with flavine cigarette drain.

September 8, 1918. Right hand improved, wound slightly septic. Bacteriologically staphylococci and long streptococcus.

September 29, 1918. Right hand still more improved, still slightly weaker than left. Face and leg normal. Subjective numbness of second, third and fourth fingers and distal half of corresponding portion of palm. Clinically appreciates cotton wool touch, pin pricks, &c., normally. Tendon jerks slightly exaggerated on both sides equally. Evening headache, slight; no giddiness. Wound healed save for two small spots.

September 30, 1918. Evacuated.

Case 7.—*Scalp wound over right motor area. Cranium intact. Jacksonian epilepsy. Trephined, extradural clot. Recovery.*

Private T. P. (Series No. 15). Bullet wound over right parietal bone, 4 in. long, crosses lower end of Rolando, August 27, 1918. Two holes in steel helmet 6 in. apart. Admitted No. 14 General Hospital, August 29, 1918. Unconscious for a few minutes after being hit. Headache ++, low frontal. Vomit 0, nausea +, palsy −; weakness left side of face; left hand grip weak; finger movements retained but slow, subjectively hand is numb and stiff. Elbow and shoulder practically unaffected. Hand was all right when first hit, but became weaker as he walked to aid post. Leg normal. No aphasia. All tendon jerks exaggerated, ++. Plantar reflexes strongly flexor. Pulse 60. Mentally clear; slightly drowsy. X-ray, no fracture detected.

August 29, 1918. Operation: Novocain-adrenalin anæsthesia. Wound excised *en masse*, bone bared, slight bruising in diploe, no fracture. Closed with flavine cigarette drain.

August 31, 1918. Neurologically no improvement.

September 1, 1918. At 6 p.m. patient had a severe Jacksonian seizure

lasting thirty-five minutes. Whole of left side of body involved, but especially face and hand. Operation: Novocain-adrenalin. Wound re-opened, 1-inch bone disc removed, extradural clot found some 6 mm. thick. Bone nibbled away leaving an oval defect 3 in. long. Clot sponged away. Wound closed with flavine cigarette drain. After operation patient had the common post-epileptic paralysis of left arm.

September 2, 1918. Arm recovering; Todd's paralysis passing off. Elbow and shoulder movements normal.

September 9, 1918. No further fits; hand now quite recovered, fine movements can be executed firmly and rapidly, but not yet quite normal. Subjectively, hand is still a little numb. Face recovered.

September 17, 1918. Hand is now normal. Face, arm and leg normal. No headache, giddiness or nausea. Tendon jerks slightly exaggerated. General condition excellent. Pulse runs 64, 72, 66, 64; temperature 98° F.

October 13, 1918. Seen in England. Up and about; no headache, no giddiness; arm and face normal.

Case 8.—*Scalp wound over left parietal field. Cranium intact. Paresis right arm. Jacksonian fit. Recovered.*

Lance-Corporal J. G. (Series No. 59). Shrapnel wound over left parietal bone 2 in. from mid-line and post-Rolandic, September 2, 1918. Wound overlies middle of left parietal field. Half-inch hole in steel helmet, missile came directly from above. Complications: flesh wounds of right arm and thigh. No vomit, no nausea. Hand and arm felt numb after wounding. Unconscious −, stunned +, headache +. Scalp wound excised in — Casualty Clearing Station, September 3, 1918, together with thigh and arm wounds; no fracture of skull. (Admitted No. 14 General Hospital, September 4, 1918.) Wounds clean. On September 8, 1918, patient had a brief Jacksonian fit limited to right arm. Post-epileptic Todd's paralysis of right hand and arm; face and leg normal. Pulse 68. Put on 360 gr. of bromide every twenty-four hours.

September 11, 1918. No further fits. Bromide stopped.

September 13, 1918. Hand and whole arm still weak; has a wound on the right arm which interferes with movement and makes it difficult to judge the exact weakness due to the cerebral injury. Fingers a little clumsy at rapid co-ordinated movements, but grip becoming strong.

September 23, 1918. No further fits; hand recovered. Evacuated.

October 23, 1918. Heard from; still has headache; says the strength has not returned to his arm (hysterical relapse).

In this case there were very slight evidences of underlying cerebral injury and the Jacksonian fit came as a surprise. As it was not repeated and seemed to be held in control by the large doses of bromide given, lumbar puncture was not performed.

Case 9.—Scalp wound over right motor area. Cranium intact. Three Jacksonian fits. Lumbar puncture twice. Recovery.

Private W. H. (Series No. 80). Shrapnel wound over right parietal bone, 4 in. aside from mid-line running forwards from a level 1 in. above inion for 3½ inches. Wound just reaches motor cortex at its anterior end. September 18, 1918. One hole in steel helmet behind; missile escaped between brim and head, tearing the scalp. Wound excised in — Casualty Clearing Station; no bone injury, September 19, 1918. Admitted No. 14 General Hospital September 21, 1918. Was unconscious first half-hour, then walked over two kilometres. No headache; no vomiting; nausea at first +. Slight weakness of left hand, tendon jerks +, equal. No aphasia. Slightly drowsy. Pulse 48.

September 26, 1918.—Patient has had one Jacksonian fit during the past night and two this morning. The last fit was very severe, and of long duration (forty minutes), controlled finally with chloroform. Was very stertorous. Pulse 60, 56, 52. Lumbar puncture under novocain: 40 c.c. clear cerebrospinal fluid withdrawn, under high tension. Bromide, 360 gr. in twenty-four hours.

September 27, 1918.—Better; no further fits. Headache, frontal, ++.

September 28, 1918.—Still drowsy, but no fits; moves left arm but it is weak. Lumbar puncture: 15 c.c. clear cerebrospinal fluid withdrawn; tension still higher than normal, but less than before.

September 29, 1918.—All headache gone; less drowsy. Bromide stopped.

October 14, 1918.—Is now quite normal. Hand grip strong; no headache. Pulse runs 68, 70, 84, 80, 90.

In this case the impact of the missile was evidently greatest at the anterior end of the wound, where it reached the motor cortex, as its main part lay over the parietal field. There was no notable sensory upset.

(*b*) *Contusions of the General Sensory Cortex.*

There was one case which was particularly interesting. In the first place it is an example of the manner in which the effects of a cerebral contusion may rapidly wear off, leaving a residuum of greater chronicity, for after being hit he was hemiplegic for a time, but the leg very rapidly recovered. In the second place it shares, with Case 6, already described, the distinction of presenting very definite sensory changes, which persisted long after the palsy had recovered. It is therefore better as an example of contusion of the sensory field than of the motor area. These two cases should be considered together. The clinical picture of the second was this:—

Case 10.—Scalp wound over left motor cortex and sensory defect. Cranium intact. Transient hemiplegia with persistent sensory defect. Trephined. No extradural clot discovered. Recovered.

Private H. W. (Series No. 60). Sniper's bullet wound over left parietal

bone, 5 in. above and 1 in. behind external auditory meatus, runs across Rolando on to pre-central gyrus.

August 29, 1918.—Admitted No. 14th General Hospital, August 30, 1918. Unconscious −, stunned +. Headache ++, "fixed." Vomit −, nausea −. When hit, temporarily lost the use of right arm and leg. Lay in a shell hole for six or seven hours, and whilst lying there power returned to leg. This happened within about half an hour. At dusk, walked about a mile to dressing station. On admission to No. 14 General Hospital hand was still quite numb, especially along the ulnar border of forearm and hand. Right hand grip was weak but not feeble; finger movements clumsy. No facial palsy; no aphasia. Tendon jerks normal; plantar reflex, flexor. Radiograph, no fracture.

August 30, 1918.—Operation under novocain and adrenalin. Wound excised; no bony injury found. In view of neurological findings, 1 in. bone disc removed. No fracture of inner table, no extradural hæmorrhage. Brain pulsating freely. Closed with flavine cigarette drain.

September 1, 1918.—Wick removed. Leg quite normal. Inner three fingers of left hand and ulnar border of arm slightly improved, but still numb. Feels cotton wool touch and pin-prick. Grip now strong.

September 7, 1918.—Numbness improved but still present; is a subjective numbness; cannot describe it properly; muscles do not feel supple enough.

September 20, 1918.—Grip now very strong; can write, but faint subjective numbness remains. Clinical tests for anæsthesia (wool, pin-prick, deep pressure) normal. Headache +, high frontal. Cranial defect is strong, concave, pulsates visibly. Tendon jerks arms absent, legs normal, ankle clonus two beats both sides.

September 22, 1918.—Evacuated.

Both this case and Case 6 presented a numbness of the ulnar portions of the hand, involving the inner three fingers. They are good examples of pseudo-radicular anæsthesia of cortical origin, and in the latter stages both exhibited what Head has called "introspective" anæsthesia. Unfortunately, rough tests only were made, but no doubt the joint sense and power of fine discrimination would have been found defective at first, had they been tested.

(*c*) *Injuries of the Visual Cortex.* (*Four cases.*)

Four examples of visual defect from cortical contusion occurred amongst these cases. The area striata occupies a comparatively sheltered position, less exposed to superficial trauma then the motor area and that for common sensibility. So that, unless there is a direct injury over the occipital pole, vision is not likely to suffer, and if the trauma is a direct one, the cranium will probably be fractured, and

such cases are not being described in this series. It may be noted, however, that in my depressed fracture series, fifty-one in number, visual upset occurred in six out of nine possibles. Certainly the visual cortex is no less susceptible to trauma than the other cortical projection areas, and my first impression was that it is more so.

The concussional changes clear up rapidly; thus two had normal visual fields and normal acuity within a week (one in six days, one in seven), whilst only one had a persistent scotoma, lower quadrantic, when evacuated nineteen days after the injury. In this last case, the affected visual field had recovered to a very appreciable extent in that time.

In Case 11 outlined below, the trauma fell over both occipital poles and in his case acuity was greatly depressed without noteworthy interference with the peripheral field. A central scotoma was present at first, but it cleared up and at the end of seven days vision was normal and he could read the newspaper comfortably. When the blow falls to one side of the mid-line of the occiput, no doubt the falx cerebri exerts an influence in limiting the concussional change to the near pole of the hemisphere only.

Hine has considered these concussional changes in detail, and gives charts showing the progressive diminution of the scotoma as the contusional effects pass away.

Case 11.—*Scalp wound over left occipital lobe. Cranium intact. Severe contusion visual cortex. Lumbar puncture. Recovery.*

Private J. W. (Series No. 8). Aeroplane bomb wound left occiput, almost in mid-line from inion forward for 5 in., August 13, 1918. Sutured in — Casualty Clearing Station. No bone injury. Admitted No. 14 General Hospital August 14, 1918. Unconscious for some hours after wounding. Headache ++, fixed. Drowsy. Tendon jerks exaggerated, equal. No vomiting. Vision: Sees a white mist only; can just see people as shadows if they are between him and the window.

August 18, 1918.—Vision improving daily; can see across the ward; counts fingers correctly. Sees people to-day, but acuity depressed, for their faces are blurred. Visual fields equal and not contracted; small central scotoma.

Lumbar puncture: 20 c.c. of cerebrospinal fluid withdrawn; clear; tension normal.

August 22, 1918.—Visual fields normal; can read to-day; vision seems to have recovered completely.

October 10, 1918.—Heard from; says eyesight is bad; has severe headache and cannot sleep: "sorry to say my eyesight has improved very little"; probably a hysterical relapse.

Case 12.—*Scalp wound over left occipital lobe. Cranium intact. Hemianopsia in right field of vision. Recovered.*

Private C. N. (Series No. 73). Shell wound of scalp, 3 in. above inion and 1½ in. to left of mid-line, November 4, 1918. Wound overlies left occipital lobe. Excised widely in — Casualty Clearing Station; no bone injury. Admitted No. 14 General Hospital November 7, 1918. Widely open excised scalp wound running from mid-line 3 in. laterally. Needs a plastic operation to close wound as edges cannot be approximated. Never unconscious; no vomiting. Headache +, occasional, "fixed." Tendon reflexes exaggerated on right side; arms +; legs ++; left side normal. Pulse 56. Vision: Complete hemianopsia up to fixation point in right field of vision.

November 8, 1918.—Operation, novocain-adrenalin anæsthesia. Cushing's "Isle of Man incision" for plastic flaps. Flavine wash. Suture with flavine cigarette drain. Bone uninjured.

November 9, 1918.—Vomited once early this morning.

November 11, 1918.—Drain removed. Very dull mentally. Pulse has run 48, 56, 60, 50, 56, 56.

November 14, 1918.—Still drowsy; lumbar puncture performed; 25 c.c. clear cerebrospinal fluid withdrawn. Tension +.

November 16, 1918.—Much better and brighter.

November 23, 1918.—No headache. Tendon reflexes normal, but ankle clonus two beats, both. Vision improved; residual scotoma in right inferior quadrant slightly invading superior. Can read easily.

IX.—Contralateral Cerebral Contusion.

Evidences of contralateral cerebral contusion were noted in four cases, in all of which the motor cortex was the sufferer. In these cases there was increase of the tendon reflexes on the same side as the scalp wound, but the brain lesion was never so severe as to cause more than a numbness and slight weakness of the hand at the most, a declared palsy was never seen. A slight contralateral meningo-cortical hæmorrhage was probably present, as the disability rapidly wore off. The following is an example, and represents the mildest form which local brain contusion can take. The signs are definite enough to leave little doubt as to the actual condition present.

Case 13.—*Scalp wound over right parietal eminence. Cranium intact. Contralateral injury left motor area. Recovery.*

Lance-Corporal A. M. (Series No. 63). Shell wound right parietal eminence, November 4, 1918. Admitted No. 14 General Hospital November 6, 1918. Wound is small and superficial. Never unconscious. Headache +, left parietal. No vomiting nor nausea. No palsies. Tendon reflexes, arms normal, legs ++, inclined to be clonic, right more than left. Ankle clonus four to five beats right, nil left. Pulse 64.

November 12, 1918.—Pulse 48. No headache. Right side tendon jerks (i.e., same side as head wound) more active than left; clonus six beats right side. Pulse running 64; 60, 50, 68, 48. Evacuated, United Kingdom.

November 13, 1918.—Heard from. Very well; slight giddiness only.

This was evidently an injury of the left parietal cortex by *contre-coup*, and presents evidences of a very slight contralateral injury in the form of increased tendon reflexes without a sign of paralysis.

X.—Pathological Anatomy of Cerebral Contusion.

As all of these scalp wounds recovered, one cannot say from experience exactly what the lesion was, but presumably it took the form of a slight meningo-cortical hæmorrhage. This could rarely have been large for two reasons: in the first place the palsies rapidly cleared up, which they could not have done had the cortical hæmorrhage been of any magnitude, and in the second place the cerebrospinal fluid was clear and untinged in those cases where it was withdrawn, and was not even yellow from old hæmoglobin staining, a discoloration one not infrequently finds after severe head injury. The only observations known to me which illustrate the pathological changes underlying a simple increase of tendon-reflexes and ankle clonus of cortical origin, arise out of the very interesting series of contralateral contusions associated with penetrating head wounds published by Duperié [3]. He found, at post-mortem, patches of meningo-cortical hæmorrhage in twelve cases and severer injuries in six more. No doubt a disorganization of brain substance or a severe intracranial hæmorrhage is the pathology underlying those deaths which rarely occur in scalp wounds pure and simple (Cushing, *loc. cit.*) and may occur in lesser cases. Sometimes the disturbance may amount to no more than a local œdema, or even a commotion without gross pathological change. A continuous slight cortical stimulus, which becomes subliminal under certain ill-defined circumstances of fatigue and of changes in the circulation, seems to be the cause of Kozhevnikov's syndrome.

XI.—Summary.

An analysis of the neurological symptoms and signs presented by a series of fifty-four scalp wounds treated at the base in France shows how frequently such signs are present. In only five were no such evidences found. Two types of cases must be distinguished, those in

which the changes are concussional and general, and those in which signs of a definite local cerebral contusion make themselves apparent. Seventeen cases of localized cerebral contusion were found in this series (31·5 per cent.), but reasons are adduced in the text for this figure being too low. Something over 40 per cent. is probably more accurate. This is a large number and the present series is too small to render dogmatic assertion permissible. But there is no doubt whatever that the neurological signs of underlying cerebral mischief in scalp wounds have been greatly neglected in the past; the eye has seen only the wound of the scalp and the mind has travelled no farther. In the majority of cases the symptoms are of a transient character and are not often very apparent (save in the case of Jacksonian seizures). Further the patients rarely associate the numbed or weak hand and the contracted visual field with the head wound and do not mention the subject spontaneously.

In none of these series was there any injury to the skull, yet there were eleven definite local contusions of the motor cortex, four of the visual, and two more in which a motor lesion was associated with a sensory disturbance of the hand. Three presented Jacksonian seizures, and three were trephined on the neurological evidence; in two, an extradural clot was found; in one, nothing abnormal. There were signs of contralateral injury by *contrecoup* in four cases.

This is sufficient to show that scalp wounds offer a definite field for neurological investigation, though scalp wounds in civil practice will probably not be so fertile a field for exploration, as the force which produces them is usually less than that of a high-velocity projectile.

There is a moral to be drawn from the above findings with respect to the assessment of pensions. It must be remembered that whilst the wound of the hairy scalp may have been in itself a trivial thing, many men may have suffered a cerebral injury of no little moment, and this must be given adequate consideration in the medical boarding of such subjects.

In conclusion, I must tender my thanks to several people: to Colonel Webb-Johnson, C.B., D.S.O., for collecting the head patients together for me and for arranging special facilities for working up the cases for publication; to Colonel Gordon Holmes, C.M.G., for his help and advice on the clinical side, and to Colonel R. J. C. Thompson, C.M.G., D.S.O., the officer commanding No. 14 General Hospital, for permission to publish these cases. Nor can I close without thanking Major C.

Mackenzie, O.B.E., and Captains R. S. Dobbin, O.B.E., and R. F. Young, M.C., who have kindly operated upon some of these patients for me.

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SOME BIOLOGICAL EFFECTS DUE TO HIGH EXPLOSIVES.

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QUITE early in the course of the war the symptoms of nervous origin exhibited by a group of the soldiers who had been subjected at close range to the detonation of high explosives excited widespread interest and attention. Never before had such a mass of material been presented for investigation, but the underlying changes of the condition, then termed "shell-shock," were wholly obscure. Mott [Lettsomian Lectures, The Medical Society's *Transactions*, Vol. XXXIX, 1916] in two cases which came to autopsy described multiple punctate hæmorrhages in the substance of the brain; and the view that the condition was due to more or less gross structural damage of the central nervous system was, for a time, widely held. As time went on, experience showed such a view in its entirety and for the majority of patients at least, to be untenable, and the pendulum has gradually but steadily swung to an opposite extreme. At the present time the very term "shell-shock" is taboo, and in the Services has been replaced by the equally unsatisfactory one of "neurasthenia." This change in terminology indicates very clearly the present general attitude of workers and observers on this subject: an attitude which evokes emotional factors as the sole cause of of all neuroses, both those of peace and war. Far be it from us to deny the important influence of the emotions in such conditions, for the evidence that the emotions in many, if not in a majority of, patients play a fundamental part appears conclusive. At the same time one meets with a large number of patients suffering from the neuroses of war in which the emotional factor does not appear to be primary, and cannot be considered as causative. In such patients, therefore, a purely psychogenic explanation will not suffice. Observation of this group reveals that physical or "commotional" factors have been operative.

First one can distinguish a sub-group in which the ætiological factor is "direct concussion" produced by the impact of missiles—either fragments of shell or earth—upon the tissues overlying the central

nervous system, but in which the brain, cord, and membranes have not been damaged by the missile. The existence of this group has been noted, but in this country at any rate its importance has been very largely overlooked, and the symptoms which distinguish it from the psychogenic group have not been sufficiently generally recognized or clearly perceived to ensure its acceptance as a definite type. We consider that the symptoms of "direct concussion" are distinctive, and shall refer to them in detail later on.

A second sub-group which has been discussed—mainly by the French—is that which may be termed "indirect concussion." In this, although there is no direct concussion in the ordinary sense of the word, the patient was sufficiently close to the bursting of a shell as to be subjected to the sudden violent variations in pressure which accompany the detonation of high explosives.

A third sub-group, and one to which I have failed to find any reference in the literature, is that in which the ætiological factor appears to be the fine, extremely rapid vibrations which are one of the less known products of the detonation of high explosives. These vibrations are capable of agitating the nervous system in such a way as to produce a condition clinically closely resembling that which results from excessive emotion.

If the above contentions be verified, the neuroses of war may have either a psychogenic, or a physiogenic, or a mixed ætiology.

The thesis to be put forward in this paper as a result of experiments is, that not only is the hypothesis of a purely psychogenic origin inadequate to account for all the neuroses of war, but that definitely physical factors also play an important pathogenic rôle.

Whatever be the origin of the "shock" it must be assumed to have some physical basis, just as must all normal processes, though this simple deduction seems often to have been lost sight of. As Purves Stewart has put it, "the old definition of a neurosis as a nervous disease devoid of anatomical changes is inadequate. Disease without some underlying physical basis is inconceivable. The lesion need not be visible microscopically; it may be molecular or biochemical."

As to the nature of the changes continually taking place, either in so-called "normal" or in diseased processes, practically nothing is known; yet that emotional shock does in some way, no matter how slight, modify them is generally conceded. It is not difficult then to allow that the grosser physical agitations, such as those referred to above, are likely to exert an even more profound influence upon the

delicate adjustment within the nervous system. Whether this be brought about by rendering the subcortical centres more excitable, or by inhibiting the higher centres, or by any other means, the clinical picture is one of a relative inefficiency of normal cortical control.

The fact that, at first sight, the immediate syndrome in typical examples of purely emotional shock is opposed diametrically to that in the commotional group—viz., excitation as opposed to stupor or loss of consciousness—need not be interpreted as implying that the underlying physiological events differ widely either from one another or from the normal. It would seem more helpful to regard them as a matter of degree rather than of quality.

This speculation is merely offered as a suggestion, and one must frankly admit that in spite of many efforts no knowledge which can be regarded as final has been acquired in this line of investigation.

The conditions under which "shell-shock" arises in man render accurate observations extremely difficult. It, therefore, seemed advisable to carry out experiments upon animals in such a way that the weight of the explosive used could be kept constant, its nature and composition known but varied at will, the actual distance of the animal from the centre of detonation measured, and other factors also accurately taken into account.

With this object in view the experiments detailed below were undertaken.

Before setting them out, however, it will be well to consider briefly what is understood by an explosive and what are its essential properties.

An explosive may be defined as a substance capable of being suddenly transformed into hot gases, which at the moment of their formation tend to occupy a far greater volume than the original substance, and consequently exert a great pressure, in every direction, upon their immediate surroundings.

The pressure exerted by some explosives exceeds 300 tons per square inch. The amount of destruction which can be accomplished by an explosive under the most favourable circumstances is known as its "power." A rough empirical measure of this "power" is obtained by multiplying the volume of the gas produced by the heat generated in the process. The shattering or disruptive effect—"brisance"—is, however, mainly dependent upon the rapidity with which the change takes place. A slow explosion has the effect of a relatively prolonged push, a rapid one that of a sudden sharp blow as

from a hammer. In the case of "high" explosives the chemical change is propagated as a wave—"the wave of detonation"—through the mass at a velocity exceeding 10,000 metres per second.

The criteria which determine whether an explosive shall be called "high" are thus the production of a great volume of hot gas in so exceedingly short a period of time as to be practically instantaneous; —the shorter this time factor the "higher" the explosive.

The force that must be transmitted to any given explosive in order to cause detonation is termed its "tonal standard." For example, if a sudden blow approximating 250 tons per square inch is required to detonate an explosive this constitutes its "tonal standard" or degree of sensitiveness.

The disruptive effect of a high explosive may be calculated by multiplying its "power" by its "velocity of detonation." When a high explosive is detonated there arises, first, a sudden terrific blow which exerts a compressing and shattering force upon its surroundings in every direction. This is instantaneous, and is immediately followed by an equally sudden decompression. Thirdly, rapid oscillatory or vibrating movements are set up, which only gradually die down. The nature of these vibrations requires further investigation, but it seems probable that in addition to the material, molecular vibrations, there arise also ethereal vibrations of somewhat the same order as those utilized in wireless telegraphy. However this may be, each of the three results just noted requires analysis when we are considering the effects of detonation upon living organisms.

Another interesting and important property of explosives is that when a wave of detonation, started at a considerable distance away, is transmitted to a second suitable source, detonation of the latter may result. Even if the distance be too great or the transmitted detonating wave, for any other reason, inadequate to excite immediate detonation in the second substance its physical state becomes altered in such a fashion as to render it more unstable; and a series of detonating waves just below the tonal standard will *eventually* cause its detonation.

The above are, briefly, some of the more essential general characteristics of high explosives. For military purposes these properties have been taken advantage of in the filling of shells, bombs and grenades in order to secure:

(1) "Fragmentation" of the container—shell or bomb—the lethal effect in this case being dependent upon the flying fragments.

(2) "Brisance" or disruptive effect due to the violence of the detonating wave.

(3) A deliberate combination of (1) and (2).

There is a further effect which will be discussed later: viz., the purely demoralizing effect which is produced by the wave of detonation outside the sphere within which it causes any demonstrable physical destruction or wounds.

Evidence will be brought forward to show that the Germans paid special attention to this peculiar effect, and arranged their shell-fillings in such a way as to enhance it.

This is fully in keeping with other of their methods of warfare, and might be described as "frightfulness by detonation."

With the obvious effects of "fragmentation" this paper does not concern itself. Attention will be directed entirely to the effects of detonation, and even here mainly to the indirect rather than to the more obvious direct effects; the latter of which will receive merely passing mention.

If a high explosive be detonated at a point X, certain zones can be mapped out around this. Three such zones may roughly be distinguished, their radii depending, amongst other things, upon the weight of explosive employed. It will perhaps be helpful to give a short general summary of the findings which lead to the establishment of these zones before entering into details of actual experiments. Zone A is delimited by the extent of obvious gross disruption, and may be termed the "zone of brisance"; within it a crater is formed, barbed wire and other obstacles are blown aside, broken and distorted; animals usually killed and lacerated; other high explosives immediately detonated.

Outside this zone is a second one, B, which must be rather more fully considered. It may be termed the "zone of decompression," for the disturbances in biological processes which take place within it seem largely attributable to this factor, though coarse jarring and shaking movements are also of importance. In zone B the gross effects of shattering and disruption are no longer evident; animals placed in it (and protected from flying fragments arising from zone A) are generally "concussed" without showing signs of any external injury; only sensitive explosive substances, whose "tonal standard" is somewhere near that of the primary explosive, detonate, and even their explosion does not invariably occur. The outer boundary of this zone cannot be sharply defined, but beyond it there can be named a zone, C, in which the effects of detonation are modified further. In zone C the effects

upon animals vary considerably, but as a rule a short transitory state of stupor followed by a stage of excited confusion is witnessed. High explosives placed in zone C only detonate if they have the same tonal standard as the substance employed at X, yet if they are left in position during a series of observations the fact that their stability has been thereby diminished can easily de demonstrated experimentally. Explosives after subjection to this treatment are always dangerous and require very careful handling.

The outer margin of zone C shades off gradually.

Experiments were first carried out in water, the test animals being fish (perch). A depth charge of 6 oz. gelignite was used. Fish in zone A were rendered obviously *hors de combat*, showed gross lacerations—especially of the gills—and were sometimes torn in pieces. These findings might well have been anticipated, and may in any case be passed over as not germane to our subject.

Fish in zone B, after the detonation, floated in an almost vertical position, but slightly inclined with their ventral surfaces uppermost. At this early stage their mouths protruded just above the surface of the water, and the whole of their bodies were rigid; if the fish were pushed down to a depth of about 2 ft., they sank slowly to the bottom of the tank, and there remained. The first reflex shown by fish in this zone was erection of the dorsal fin upon stimulation of the skin to either side of it. Next there occurred spasmodic movements of the opercula and gills; these were violent and irregular. In those fish which eventually recovered, swimming movements began to be possible about half an hour after the detonation. At first the movements were only carried out in response to stimulation of the abdomen—stroking with a piece of stick—and they carried the fish only forward in a direct line; no turns were observed at this stage even when an obstruction was encountered. These first swimming movements occurred with the ventral surface uppermost, and lying almost flush with the surface of the water. Thus it can be said that up to this stage the fish had lost their power of equilibration, and with this the whole of their orientation in life.

The majority of the perch which attained the power to swim as just described gradually became more and more active, and after passing through a side uppermost position, and remaining quiescent for long pauses, they righted themselves and began to swim about in the ordinary way. In about twelve hours after the detonation, those fish which had not entirely succumbed were to all appearances completely normal.

Dissection of the dead ones showed, as a rule, hæmorrhages in the upper region of the spinal cord and medulla, congestion of the foreparts of the brain, and a number of hæmorrhagic points in the mid-brain and basal gangliar region. The gills and other viscera were congested, and often showed areas of hæmorrhage. The extent of these lesions was naturally variable.

Dissection of fish taken at random immediately after the detonation revealed either varying degrees of the above-mentioned lesions, or by macroscopic examination nothing abnormal was discovered. It is regrettable that at the time these experiments were carried out we had no facilities for preparing sections or making microscopical examinations of our material. We are, however, carrying out further experiments and making microscopical preparations, the results of which we hope to publish later.

The results of detonation towards the inner boundary of this zone would seem to be due to sudden decompression and to the rude shaking which the creatures received. Towards the outer margin of B zone and the inner region of C zone the effects upon the fish could not be sharply distinguished; the severity of the symptoms gradually diminishing (and the anatomical lesions becoming rarer) with the radius of the circle described from the centre of detonation. Fish well out in C zone swam about vigorously in a disturbed and excited manner, but though they dashed about wildly and apparently haphazardly, it was generally noticed that the movements which they made carried them away from X (the centre of detonation). A few came to the surface and splashed about; when netted, no physical abnormality could be demonstrated, and those returned to the water soon behaved in a completely normal manner.

In considering the effect upon fish of vibrations thus set up in water, one must not be unmindful of the great development in these creatures of sense organs which are directly susceptible to stimulation of this type. We refer to the pre-oral mucous canals which enable a fish deprived of its eyes to guide itself along tortuous passages by the delicate appreciation of the reflected pulses of water. Also the lateral line organ which subserves similar functions. It is, therefore, conceivable that the effects of violent vibrations may be in part due to excessive stimulation of these numerous special sense organs; the fish being, as it were, swamped by the flood of incoming impressions. If this be so, the shock, though physical, would be more accurately described as of neurogenic than of commotional origin.

Probably both factors play a part, and in any case it is impossible to discriminate between them in the experiments as carried out. It is well known that in man unconsciousness can be produced by purely reflex stimulation of the skin, of the eyes, of the ears, &c., e.g., by bastinado, by extremely bright lights, as of furnaces, and by rotation in a chair. In such cases the whole ego is swamped by an excessive flood of afferent impulses which produces a condition of neurogenic shock, there being no "commotio." We have no evidence which leads us to think that neurogenic shock, as above described, plays any appreciable rôle in the causation of the war neuroses, and shall not refer to this aspect of the subject any further.

Experiments with mammals—rats and mice—on land were carried out in the following ways: Perforated zinc cages were used, partly to fix the position of the animals and partly to protect them from flying fragments. These cages were distributed at measured distances about the point X. The charge was standardized to 3 oz. of explosive. In one series of experiments the charge was buried in a hole 6 in. deep in order to imitate a shell which penetrates the ground before detonating. In this case a major portion of the force seems to be directed conically in an upward direction and there is less lateral spread along the surface of the ground. Using 3 oz. of gelignite in this way, a crater measuring about 18 in. across was formed; the B zone extended roughly 12 in. outside this, and the C zone another 20 in. or more. That is to say, that under these conditions demonstrable results were produced at a distance of from 4 to 5 ft. around X. In a second series of experiments the charge was not earthed, but simply laid upon the surface of the ground in order to imitate a shell exploding immediately upon light contact.

In this case the crater formed was much smaller, but the force expended in a direction parallel to the surface of the ground more extensive, and the boundaries of the zones lay farther out from X. With these exceptions the results in the two series of observations were essentially the same.

In zone A cages in and immediately outside the crater formation were simply blown away and distorted, the contained animals being killed or severely wounded by direct violence. These, together with animals wounded by fragmentation or the shattering of the cages, will not be further considered. Those animals which escaped this direct trauma were invariably rendered unconscious, their eyes were blood-shot and frequently there was external hæmorrhage from the ears,

nose and mouth. On dissection varying amounts and degrees of internal hæmorrhage in the viscera and central nervous system were revealed; the alveoli of the lungs were almost always found to be to a certain extent ruptured. These gross changes would seem in part attributable to the direct blow of the displaced air which strikes like a solid substance, and in part also to the effect of exceedingly rapid decompression immediately succeeding this. At the inner margin of zone B the findings, though in the main similar to those just described, were very much less in degree. When cages were shielded by a small mound of earth from the direct impact of displaced air, the animals were sometimes found to be dead even though, except for injection of the conjunctivæ, they exhibited no signs of external injury, and upon dissection the only abnormality disclosed by coarse examination was a general capillary engorgement—especially noticeable in the central nervous system and meninges.

Further out in zone B a state of stupor or transitory loss of consciousness was an almost constant result. The duration of this state varied inversely with the distance from X.

During the course of recovery twitching movements of the limbs were often present, and then the animal, if stimulated by appropriate physical agents, showed massive and exaggerated reflex reactions. For example, the application of a pin-prick to one hind limb might at this stage be followed by a bilateral flexion of the hinder extremities, or even by a generalized convulsion.

There was frequently considerable difference in the activity of the reflexes on the two sides of the body—a hemiplegic distribution; but as a rule the fore limbs were more severely affected than the hind limbs, and showed weakness, as evidenced by inco-ordination and dragging, after the latter had regained normal movement. Reflex responses, though vigorous, died away quickly, but were often succeeded by a weaker repetition even when no fresh stimulus was given. Rapid fatigue of the response on repeated stimulation was a noticeable feature.

By dissection no gross macroscopical evidence of internal injury to such animals was discovered, though in some cases there was capillary engorgement as in animals nearer X. Whether this should be taken as indication that vaso-motor changes play a part in the production of the associated phenomena we have no means of determining.

Animals left alone during the stage of recovery gradually began to behave in a manner, to them, more normal, though for a considerable time their conduct, postures, and gaits were awkward and abnormal.

The severity of these disorders varied greatly from animal to animal and consequently it was impossible to deliminate precisely, from biological observations, the borders of the several zones. In the C zone, animals crouched down and huddled themselves together whenever a detonation took place; after this state of dimininished activity, a state of apparent excitement with increased restlessness was generally observed. If, however, animals were left exposed in this position during a series of experiments they invariably crouched down as flat as possible and seemed to be in an absolutely stuperose condition. When liberated they made no efforts to run away but remained for a long time motionless in a huddled-up posture. The interpretation of these latter abnormalities in behaviour is difficult. Should "fear" be allowed as the main cause, or are other more material factors also at work?

If instead of employing, in the experiments, a single explosive substance at the point X, one detonated a composite or mixed charge —standardized to 3 oz. in every instance—all the above-mentioned effects become more pronounced. The increase of effect was particularly noticeable in the C zone and its immediate surroundings.

In this connexion it is interesting to record some observations carried out upon physically and mentally fit men of an "Ammunition Proof and Demolition Section" during the course of their ordinary duties. The staff was drawn from infantry men who had some technical knowledge. They were sheltered in a well-protected dug-out about 100 yds. distant from X, the centre of detonation. In this case X was a large crater blown in the centre of the demolition ground and contained the official maximum weight for each single destruction, viz., 200 lbs.

Presumably the men were, *for ordinary explosives*, outside the zone which has been referred to in this paper as zone C.

Although the men had some technical knowledge they did not know the nature of the various explosive fillings which were to be destroyed at any given time, and it was interesting to study the differing effects of these upon them. Single simple fillings such as T.N.T., picric acid, and tetryl, rarely caused any of the men discomfort under the conditions just described, yet when mixtures such as ammonal (British), amatol (British and German), donarit and "glückauf" (German) were detonated many of the men complained of unpleasant physical sensations, e.g., "catching in the throat," "peculiar feelings in the chest," "creepy feelings down the spine," or "weakness of the legs"; others were seen to shake violently and the rate of their pulse and respirations increased.

When separated or layered fillings of different explosives having velocities of detonation which differed considerably from one another were detonated the effects were decidedly greater and several of the men under these conditions passed into a state of stupor, which was followed in some instances by violent shakings and twitching, and in one case by vomiting.

Men thus affected were not fit for duty for the next two or three days. Moreover it was noteworthy that any man who had once manifested the more intense symptoms was subsequently less resistant. And although he was fully aware that no real danger attended the demolitions he seemed to be in a state of mental anxiety, and afterwards was more easily and readily affected by the detonations than he previously had been. To use the expression of his colleagues, "he seemed to have got a sort of respect for H.E." Now one word upon the nature of these mixed and layered fillings. Examination of certain German shells shows that layered fillings were deliberately employed, although in manufacture they involve more trouble and labour. For example, the 15-cm. howitzer shell has the top half of the filling composed of a mixture of 60 parts trinitroanisol and 40 parts ammonium nitrate. This mixture yields a detonating wave with a velocity of 4,850 metres per second. The lower half of the shell is filled with dinitrobenzene which yields a detonating wave with a velocity of 6,000 metres per second. The upper and lower charges are often separated by a diaphragm of wax or wood.

This type of filling is also found in the 25-cm. minenwerfer short-shell. As the latter has not to take the grooving of a gun-tube the container need not be strong. In practice it was made of a sort of Britannia-metal which simply pulverized on the detonation of its contents. The shell, therefore, cannot have been intended to act by "fragmentation." Captured German documents reveal the fact that this type of shell was especially intended for use immediately prior to an attack, and in sectors where the enemy were well entrenched and possessed good dug-outs. Hence it is highly probable that the Germans were aware of the peculiar demoralizing effects of these mixed and layered fillings. Reference should also be made to the German "disk-granaten," known to British troops as the "oyster-grenade," and to the "stiel-granaten" known as the "potatoe-masher"; neither of these kill by fragmentation, but both are par excellence demoralizing.

It would be interesting to know if the Germans' use of these fillings

was based upon experimental findings, and if so what was the precise nature of their experiments.

Most of those who have been through a severe bombardment, either from the above-mentioned shells or from aerial bombs, can bear testimony to the peculiar demoralizing effect it had upon them, and how this state of demoralization was succeeded, owing to summation of effect, as the bombardment continued by a sort of fixed "glassy feeling," even when the shells did not explode particularly close to them. In order to eliminate as far as possible the psychic factor, which under such circumstances plays its part, it is instructive to study cases in which the effective detonation fell like a "bolt from the blue" upon individuals who were not in a state of tense expectation or fatigue at the moment of the incident. At the same time one cannot ignore the importance of the predisposing factors, which are highly complex. There is, however, as regards the type of neurosis developed, nothing distinctive about them; so far as our observations go they all seem to operate in a general way by lowering the resistance of the individual to all forms of shock.

Of all predisposing factors fatigue, both physical and mental, is undoubtedly the most important. A type of history which has attracted our attention by its frequency is that of the soldier who had been moved rapidly from one part of the front to another, and on arrival at the new sector was sent direct into the firing line. He generally says that the trenches were in bad condition, and that while exhausted on his first evening here his company were subjected to heavy bombardment. Under conditions of this sort the soldier seems particularly liable to break down either immediately or during the course of the day following.

A rest of comparatively short duration exercises a truly wonderful influence in restoring the resistive powers.

In our experience the following points are helpful in determining the nature of the primary causal factor in cases where it is doubtful.

First, to deal with cases in which "direct concussion" is the causal agent. The initial symptom is unconsciousness; often of several hours' duration, and possibly persisting for days. Consciousness when recovered does not remain clear, but the patient passes through a phase of variable length, during which he loses and regains it, the so-called "dipping of consciousness." Aphasia and sphincter troubles are common at this stage, which is frequently associated with an active delirium in which the patient re-enacts episodes of his military service. The general condition is one of extreme exhaustion: all mental pro-

cesses are sluggish, and there is great difficulty of concentration. Amnesia, both for the immediate and remote past, is a common occurrence. The voice is often altered, becoming slow, monotonous, and higher pitched than is natural to the patient. In severe cases these symptoms tend to persist for many months, and relapses are easily induced by any fatigue; we have noticed them after long railway journeys, &c. Clinically the importance of recognizing these symptoms is that the prognosis in cases of genuine direct concussion is much graver than in those giving a spurious history of concussion after being thrown down or partially buried. Also psychotherapeutic treatment is of no avail, except in so far as fixation of symptoms may have supervened in the later stages.

In such cases experience shows that prolonged rest and freedom from strain of all sorts are essential.

The discrimination of cases of "indirect concussion" requires more careful study. Unconsciousness or stupor of relatively short duration is the rule, but it is often difficult to obtain an accurate history on this point, as there is a tendency on the part of the patient to exaggerate, and corroborative evidence is rarely forthcoming. The phenomenon of "dipping of consciousness" is not observed, and active delirium of the occupational type is rare. Amnesia, though frequently present, is much less in extent, is only retrograde, and is more readily recovered than in cases of direct concussion. There is a greater tendency to the superimposition of functional troubles such as paralysis and algesias. These may develop immediately, but more commonly they come on later as the symptoms of commotional origin are recovering. If they are removed by appropriate treatment, the patient after a few weeks complete rest generally "feels as well as ever." Easily induced fatigue and diminution of power to concentrate are, however, apt to be more persistent symptoms, and the patient, in spite of his statement that "he feels quite all right," should be given a more prolonged period of freedom from strain.

Cases in which the neurosis has arisen as the result of exposure to detonation in what we have termed the C zone are naturally more difficult to differentiate from those of purely psychogenic origin. The description, already given, of men so exposed in the "Ammunition Proof and Demolition Ground" affords a better picture of the onset of the neuroses than can be got from the more complicated conditions obtaining in trench warfare. One must remember that in the latter the bombardment is more incessant; the soldier in a state of expectancy,

and possibly also of physical fatigue, all of which factors sensitize or predispose him to the effects of detonation.

In a rather disparaging way any shell exploding outside the A zone is commonly referred to as merely the "last straw," its influence thus tacitly being attributed to purely emotional factors.

It is, however, a "last straw" which cannot be lightly disregarded, and one is justified in maintaining that a sufficient number of such "straws" will cause the downfall even of the most robust. One should bear in mind the fact that the stability of an explosive is under such conditions diminished, and that it may eventually detonate. It is not difficult to conceive that physical processes which thus give rise to alterations, in the direction of instability, in a relatively simple chemical compound such as an explosive may in a similar way affect the far more delicate colloidal solutions contained in the central nervous system, either directly or indirectly. With cases of purely psychogenic origin, many of whom have never reached the danger zone at all, it is not our object to deal

An interesting question which does arise at this point is as to whether the two ætiological factors—emotion and commotion—may not operate together and thus confront the observer with a third group of patients in whom the origin of the neuroses is mixed. Obviously, if once the possibility of a physical origin be conceded, this question must be answered in the affirmative.

We suggest, further, that this is the most common occurrence, and that whichever be the primary cause of the instability, the patient, once sensitized, remains for a long time, perhaps always, hypersensitive to both commotional and emotional stimulation. Under war conditions a vicious circle is thus established.

From a large number of instances of real "shell-shock" as distinguished from those of "neurasthenia," the following is selected as worthy of report here, not because one example can be held as establishing any general principle but because it may be taken as a representative type of the group of patients in which the primary factor was "commotional," but in which this physical origin became overlaid, as is so common an occurrence, by emotional elements during the progress of the case.

A corporal, aged 22, went to France with the original Expeditionary Force and served through the Mons retreat, the Battle of the Marne and at Ypres with great coolness and courage. He liked military life and was particularly well adapted to fighting. In May, 1915, he was

one day sitting with a companion in a trench preparing some food when a large H.E. shell detonated on the parapet almost immediately above him. His comrade was killed, but this he did not know or learn until long afterwards.

For a few moments he lost consciousness, but from the account of others this period of unconsciousness must have been brief. He then went over the top, exposed himself with apparent recklessness, and rushed about in a state of oneiric delirium shouting various orders to his men. After this incident he was sent down to the Base for a rest, but in a month he was returned to his unit to all outward appearances as "fit" as ever before. Inwardly, however, he noticed a great change in himself, and found to his great disgust that he no longer could remain calm when under shell-fire.

His anger and shame at the idea of suffering from "shell-shock"—which he considered merely a polite phrase for "wind-up"—was so great that he used much effort and managed to control himself during the next two years while he remained in France. From July, 1917, to March, 1918, he was in England training as a cadet, during which time he ceased to think of all his unpleasant experiences, and when he returned to France he went with the same feeling of confidence as he did in 1914. But to his intense disgust he discovered that close proximity to shell-fire threw him into an uncontrollable state of excitement. He began to suffer from severe discomforts in the head, and felt so sleepy that he "could hardly keep awake." It now became necessary for him to avoid, by every possible trick, the occasion of a public breakdown; this he managed to achieve.

In October, 1918, he returned home on ordinary leave; on his second day in England—i.e., as soon as he relaxed control—he fell into a state of stupor and was admitted to hospital. Here, over a period of at least two months, states of stupor alternated with paroxysms of excitement and weeping. At the present time (January, 1919) he is easily fatigued, is liable to headaches, has difficulty in concentrating his thoughts, and becomes confused in traffic.

A history of this type is by no means rare, but is met with fair frequency in the Special Neurological Military Hospitals.

No useful purpose would be served by detailing a number of other similar instances, as the above case illustrates sufficiently well the points to which we wish to direct attention.

It is desirable from every point of view that cases of this type should be separated from those in which the underlying causal factor is purely psychogenic.

One cannot remain content with any classification which is based upon an arbitrary grouping of superficially similar characteristics. Every effort should be made to discriminate between the several types upon the basis of their pathogenic origin, for both treatment and prognosis are largely determined by this.

Had our patient been seen when at the Base after the first detonation one would have been justified in describing him as an instance of "shock" of purely commotional origin, and in treating him accordingly. If, on the other hand, one had seen him for the first time, and knew nothing of his previous history, in October, 1918, one might have regarded his manifestations as of purely psychogenic origin. Experience shows, however, that psychotherapeutic treatment is of no use while acute symptoms of commotional origin are present, and even when, in mixed cases, these have subsided, the progress of the patient is as a rule much slower than in purely psychogenic cases.

Although one not infrequently meets with cases in which, apparently, a single causal factor has been operative, we maintain that a careful and unbiased study of histories in the Special Military Neurological Hospitals leads to the conclusion that the combined action of the two aetiological factors is the more common event.

It seems to us that it is the failure to recognize and allow for this combined action, and the vicious circle which warfare brings about, that has led to the prevalent tendency to regard all the cases of war neuroses as emotional in origin. Perhaps another influence, making in this direction, is the fact that in the later and chronic stages of the more severe cases the pictures presented by the two types of patient gradually approximate until clinically they become identical, or at least so appear; for the most noticeable feature of shock, no matter what its pathogenic origin, is that it leads to a diminution of "higher level" control, and in its severer forms to a state of psychasthenia which shows a tendency to pass into dementia.

Conclusions.—The neuroses of war may be brought about:—

(*a*) By the action of "purely emotional shock," which at the present time is well recognized, but whose importance tends to be over estimated.

(*b*) By the action of "purely physical shock"; a study of the mechanism of which is the main object of this contribution to the subject.

(*c*) By a combination of the two above-mentioned ætiological factors; this is the most common occurrence (and after the psycho-

neurotic symptoms have been cleared up, the residual actual neurosis, which has formed a foundation for the whole disorder, is often exposed).

The object of this paper will be amply served if it help towards correcting the present tendency to regard the neuroses of war as of exclusively emotional origin, and towards gaining a more general recognition for the underlying physical basis demonstrable in a considerable proportion of them.

At the same time it seems to us to open up the whole question of the interdependence of the physical and psychic bases of hysteria and its allied conditions.

ON THE DEVELOPMENT OF THE EXTERNAL FORM OF THE HUMAN CEREBELLUM.

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Amsterdam.

THE great obstacle to the study of the morphology of the cerebellum lies in the nomenclature. In order to avoid misunderstanding, I propose to give first a table, containing the names of the grooves, fissures and lobes I intend to use. In choosing these names I have been as conservative as possible. I followed therefore the purely topographical method of human anatomy. This system recognises an upper and an under surface of the cerebellum and a posterior margin, where the two surfaces meet. The names of the fissures have been chosen in accordance with this orientation. I do not fancy the system will be satisfactory in general, but if it helps to avoid misunderstandings it will have performed its duty. It would be possible to invent an entirely new system of unequivocal terms to indicate the principal fissures of the human cerebellum. In the table preceding this research I shall add these new terms in brackets behind the older ones.

The general result of my research is that the human cerebellum at a certain period of its development is built up of ten lobes. Because these ten lobes comprise all the later parts of the adult cerebellum, I take them as the starting point for the division of the human cerebellum.

TABLE.

Fissura prelingualis
(1) Lobus vinculolingualis
Fissura precentralis [f. centrolingualis]
(2) Lobus centro-alaris
Fissura prelunata [f. culminocentralis]
(3) Lobus culminolunatus
Fissura superior anterior [f. declivoculminalis]
(4) Lobus declivolunatus
Fissura superior posterior [f. foliodeclivalis]
(5) Lobus foliosemilunaris
Fissura horizontalis [f. tuberofolialis]
(6) Lobus tuberosemilunaris
Fissura inferior posterior [f. pyramidotuberalis]
(7) Lobus pyramidobiventricus
Fissura inferior anterior [f. uvulapyramidalis]
(8) Lobus uvulatonsillaris
Fissura preuvularis [f. nodulo-uvularis]
(9) Lobus nodulofloccularis
Fissura prenodularis [f. nodiolonodularis]
(10) Lobus nodiolovelaris

It follows also from this research that the vermis and the hemispheres during a certain stage of development are well-defined, separate parts of the cerebellum : hence it is necessary to discriminate between the fissures belonging to the vermis and those belonging to the hemispheres. But because most fissures of vermis and hemispheres later join together, it will be sufficient to add the term "pars mediana" to the name of the fissure to indicate the vermis part, and the term "pars lateralis" to indicate the hemispherical division of the furrow.

A cerebellum of the middle of the third month forms the starting point of the description. In this stage of development, the cerebellar plate (lamina cerebelli [1]) has the form of a horseshoe, which embraces the brainstem. It is placed approximately perpendicular to the direction of the stem, so that we may describe a superior, an inferior and a lateral surface in respect of the main direction of the stem.

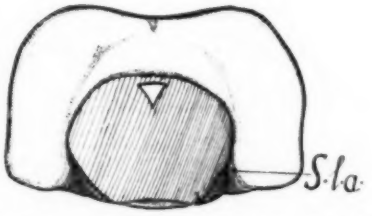

FIG. 1.—Superior surface of a cerebellum of the middle of the third month. The brainstem is cut away at the level of the cerebellar plate. *S.l.a.*, sulcus limitans ant. Enlargement × 5.

The superior surface of the cerebellar plate is nearly flat and separated by a shallow groove, the sulcus limitans cerebelli anterior, from the mesencephalon. Ventrally, the groove becomes a little deeper and broader (fig. 1). A very shallow depression, starting from the limiting groove, extends on either side over the upper surface of the cerebellar plate. Both depressions are curved towards the middle line, but in this stage of development do not yet meet there.

The superior surface passes continuously into the inferior surface. The greater part of this surface consists of a thin lamella (lamella cerebelli). Seen from the outside, it gives the impression that the lamina rapidly thins off into the lamella (fig. 2). The lamella on its posterior border is continued into the rhombencephalon. The transition of the lamella into the substance of the rhombencephalon

[1] This name has been introduced by von Mihalcovics [13].

is marked by a groove, the sulcus limitans posterior. Along the ventral border of the cerebellar plate the posterior limiting groove continuously passes over into the anterior limiting groove. The limiting groove is filled up by embryonic connective tissue, so that the true configuration of the groove is not reproduced in my drawings. The lamella cerebelli is also covered by connective tissue, which could not be removed without tearing the membrane. Several details of the lamella, e.g., the plica chorioidea, are therefore not visible.[1]

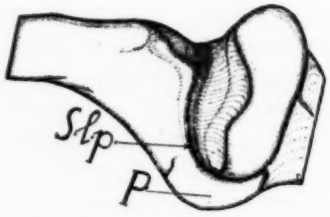

FIG. 2.—Lateral surface of a cerebellum of the middle of the third month. Same cerebellum as reproduced in fig. 1. The lamella cerebelli is covered by embryonic connective tissue, so that the plica chorioidea and several other details could not be reproduced. *P.*, pons ; *S.l.p.*, sulcus limitans post. Enlargement × 5.

The transition of the cerebellar plate into the lamella is not situated at the posterior margin of the plate, but somewhat anterior to it, so that the posterior border of the plate protrudes freely into the ventricular cavity, covered by the lamella. In fig. 2 this part of the plate may be seen shining through the lamella. This state persists during the whole development of the cerebellum and even in the adult stage, though it is less evident from the middle of the third to the middle of the fifth month.

In the middle line the cerebellar plate is thin and transparent ; this transparent spot is slightly depressed on the outer surface. Whether this depression really exists or is artificially formed by the fixation, I do not know. On the inner surface the cerebellar plate rapidly thins off towards the middle line. Hence we conclude that the middle line is a place of reduced growth in comparison with the adjoining regions of the plate. This conclusion seems to tell in favour of the view that the cerebellar plate is a structure of bilateral origin (His [9]).[2] This thin and transparent place disappears *pari passu* with the enlargement of the

[1] A more detailed description of this stage has been given by me in the "Anatomischer Anzeiger" [12].

[2] A discussion of this question is to be found in O. Charnock Bradley [5].

plate, but even in a more advanced stage of the plate the region of the middle line is still slightly depressed on the inner surface.

Another thin spot exists on either side of the middle line. Here the posterior edge of the plate shows a little notch, which runs out into a shallow groove (fig. 3). By these two lateral grooves a median portion of the plate is demarcated, which later seems to form the vermis. The lateral grooves have first been observed and described by Kölliker [10].

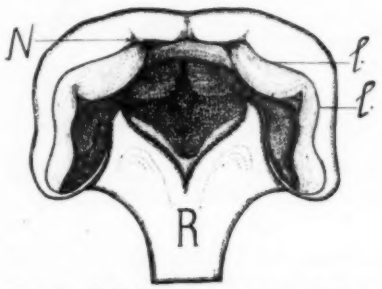

FIG. 3.—Inferior surface of a cerebellum of the middle of the third month. Same cerebellum as reproduced in figs. 1 and 2. The lamella cerebelli is torn off along the line *l*, *l*, so that the fourth ventricle is opened. The posterior border of the cerebellar plate is visible protruding into the ventricular cavity. *N*, notch in the cerebellar plate; *R*, rhombencephalon. Enlargement × 5.

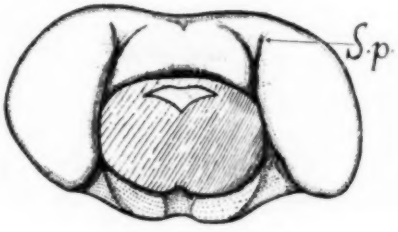

FIG. 4.—Superior surface of a cerebellum of the second half of the third month. The brainstem is cut away at the level of the cerebellar plate. *S.p.*, sulcus paramedianus. Enlargement × 5.

The next stage is somewhat older, probably the second half of the third month. In this stage, the superior surface of the cerebellar plate is more convex and more distinctly marked off from the brainstem (fig. 4). The depression starting from the sulcus limitans has developed into a shallow bifurcated groove. The medial branch of the groove curves towards the middle line, where they later join together. At the bottom of this shallow groove, the fissura superior anterior[1] makes its appearance. The field limited from behind by this groove, becomes gradually slightly elevated. In consequence of this elevation it begins to project above the regions immediately adjoining the mesencephalon. In a somewhat older stage this relation is still more accentuated (fig. 5).

The little field in front of the elevated field is triangular, resting with its base upon the tectum mesencephali. In the beginning it is indistinctly

[1] "Fissura prima" of embryologists.

marked off from the elevated field; but somewhat later a fissure appears, the fissura prelunata, which divides the two fields. The base of the field is separated from the brain stem by a fairly deep groove, the fissura precentralis, which has partly developed from the anterior limiting groove. In the depth of this groove a small white ridge is visible, the first trace of the lingula.

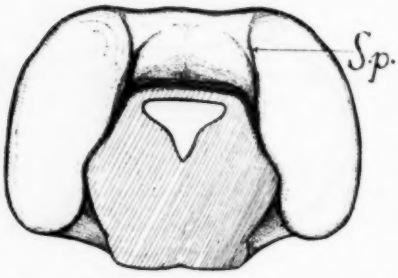

FIG. 5.—Superior surface of a cerebellum of the second half of the third month. This cerebellum is probably somewhat older than that reproduced in fig. 4. The brainstem is cut away at the level of the cerebellar plate. *S.p.*, sulcus paramedianus. Enlargement × 5.

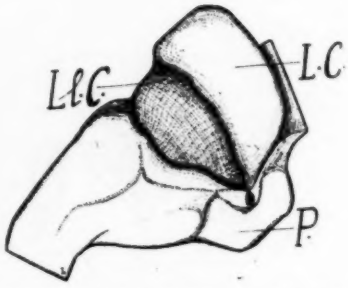

FIG. 6.—Lateral surface of the same cerebellum which is reproduced in fig. 4. The lamella cerebelli is covered by connective tissue, so that the details of the membrane could not be reproduced. *L.C.*, lamina cerebelli; *Ll.C.*, lamella cerebelli; *P*, pons. Enlargement × 5.

The lateral branch of the bifurcated groove runs in antero-posterior direction. The groove becomes flatter at this stage of development in the neighbourhood of the posterior border of the superior surface. This groove forms the origin of the sulcus paramedianus, which divides the vermis from the hemispheres. I have received the impression that the sulcus paramedianus develops from the lateral groove of Kölliker. The inferior surface has increased in size and the cerebellar plate seems to approach its completion (fig. 6). The posterior border of the plate still protrudes into the ventricular cavity, but this is no longer as evident as it was before.

The first grooves to appear upon the cerebellar surface seem to be formed by differences in growth between the regions adjoining the groove and those forming the bottom of the groove. This causes the grooves to be broad and shallow. Later, the formation of the grooves takes place by a more active process. In this case, the formation of the furrow is preceded by a proliferation of cells, in an antero-posterior direction, which is followed by the appearance of a transverse fissure, perpendicular upon the direction of the cell-proliferation. This process

resembles in some respects cleavage. The sulcus paramedianus appears chiefly, if not exclusively, to be formed in the first manner, whilst the other fissures, by which the cerebellar plate is split up into ten lobes, are principally formed in the second way. Because the two processes in the beginning interfere, it is often difficult to state the exact moment at which a fissure arises. My own material tends to the conclusion, in agreement with Kölliker [10], Mihalcovics [13], Bradley [3, 4], and Bolk [2], that the furrowing begins first in the vermis, followed shortly by the cleavage of the hemispheres. The formation of the fissures in the vermis proceeds, at least in the beginning, independently of the formation of the fissures in the hemispheres. The sequence in which the fissures appear to take their origin in the vermis is: fissura precentralis, fissura superior anterior and fissura prenodularis, approximately at the same moment; next the fissura prelunata and the fissura preuvularis; lastly, the fissura inferior anterior and the fissura inferior posterior.

The hemispherical fissure, which first appears, is the pars lateralis of the fissura prenodularis, and this fissure is very soon followed by the lateral part of the fissura preuvularis. This fact is also stated by Bradley [3] for the rabbit and the pig, by Kölliker [10] for the rabbit, and in man by Smith [19], and by Stroud [22]. The fissure of the hemisphere appearing next is the pars lateralis of the fissura superior posterior. This latter furrow makes its appearance approximately simultaneously with the vermis portion of the fissuræ inferior anterior and inferior posterior. To sum up, I find, therefore, that the fissures of the vermis begin to form before those of the hemispheres; that the first fissures of the vermis arise approximately at the same time in the neighbourhood of its anterior and posterior borders. In the hemispheres, the furrowing in the neighbourhood of the posterior border precedes a little the furrowing near the anterior border.

The period of fissure formation of the cerebellar plate is only short, so that the differences in time between the moments at which the fissures appear are very small. For this reason inversions may probably occur in the sequence, by which the fissures make their appearance. Most observers, e.g., Smith [17, 19], extend the period of furrowing over several months. This opinion is probably the result of the fact that during the development of the cerebellum certain fissures may temporarily vanish and reappear.

The next stage belongs to the end of the third or the beginning of the fourth month. The superior surface shows clearly, at least in the

case of the right half, the division of the cerebellum into a vermis and hemispheres (fig. 7). On the inferior surface the distinction is not yet so evident; this boundary is indicated by a shallow, partly interrupted, groove only (fig. 8).

The triangular field, which rests upon the tectum mesencephali, has considerably increased in size. It is separated from the brainstem by a deep groove, the fissura precentralis. At the bottom of this groove there lies concealed the white prominence that forms the origin of the lingula. From behind, the triangular field is bounded by a fairly deep groove, the fissura prelunata. The triangular field itself is still confined to the vermis, but shortly afterwards the furrows limiting the field extend laterally into the hemispheres. The triangular field, with its hemispherical appendices, forms the lobus centro-alaris. The median division of this lobe, i.e., the triangular field, is the later lobulus centralis.

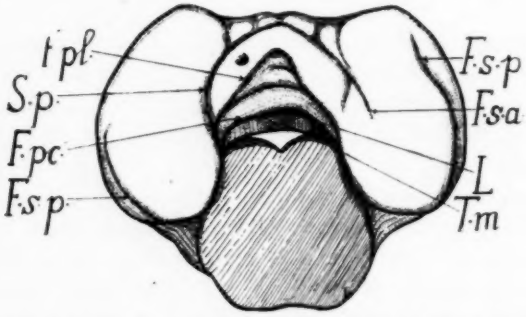

FIG. 7.—Superior surface of a cerebellum of the end of the third month or of the beginning of the fourth one. The brainstem is cut off. *F.pc.*, fissura precentralis; *F.pl.*, fissura prelunata; *F.s.a.*, fissura superior ant.; *F.s.p.*, fissura superior post.; *L.*, lingula; *S.p.*, sulcus paramedianus; *T.m.*, tectum mesencephali. Enlargement × 5.

At this early stage the lobulus centralis is already divided into two parts by a complete fissure of the second order. The superior division of the lobule shows the beginning of another secondary groove (fig. 7). These grooves are the first secondary grooves of the cerebellum to appear and they precede in their appearance the primary fissures of the central region of the cerebellum.

The prominent field situated behind and above the lobulus centralis is bordered from behind by a deep fissure, the pars mediana of the fissura superior anterior. At this stage of development it is the deepest fissure of the cerebellum and easily recognizable. Originally the fissura superior anterior belongs to the vermis, but on the left this groove

penetrates through the sulcus paramedianus and begins to extend into the hemisphere. Here it remains a short groove, which does not reach the lateral hemispherical margin.

The next groove is the median part of the fissura inferior posterior. This groove belongs to the inferior surface and is at this stage strictly confined to the vermis (fig. 8). The next groove is the median part of the fissura inferior anterior, and this groove also fails to extend as yet into the hemisphere. The fissura preuvularis comes next. On the right, this groove is limited to the vermis, but on the left it already passes into the hemisphere. The hemispherical or lateral part of the fissura preuvularis arises independently, near the lateral margin of the hemisphere, grows medially and unites with the median division of the groove.

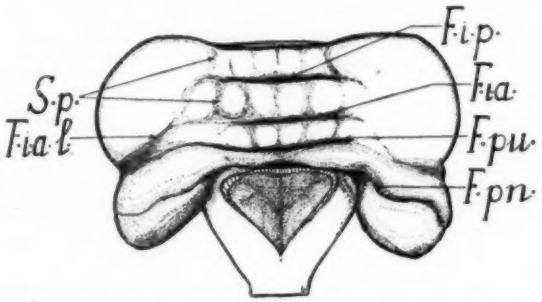

FIG. 8.—Inferior surface of a cerebellum of the end of the third month or of the beginning of the fourth one. Same cerebellum as reproduced in fig 7. *F.i.a.*, fissura inferior ant., median part; *F.i.a.l.*, fissura inferior ant., lateral part; *F.i.p.*, fissura inferior posterior. *F.pn.*, fissura prenodularis; *F.pu.*, fissura preuvularis; *S.p.*, sulcus paramedianus. Enlargement × 5.

The most posterior groove is the fissura prenodularis, which is also of double origin. The median part of this groove remains limited to the vermis. The lateral part takes its origin close to the lateral margin of the hemisphere, extends medially and then joins the median division in the neighbourhood of the sulcus paramedianus. Both divisions of this groove may arise at the same moment, but more often the median part precedes by a little the hemispherical part.

The last groove of this stage is the fissura superior posterior. This groove originates on the inferior surface of the hemisphere near the lateral border (fig. 9); growing medially, it reaches the superior surface (fig. 7). At the moment of its appearance this groove is not yet represented in the vermis, so that it forms the type of a purely hemi-

spherical fissure. When this groove reaches the neighbourhood of the sulcus paramedianus, the first vestige of a furrow appears in the vermis. This furrow extends laterally and unites with the hemispherical division of the fissura superior posterior. Smith [19] and Bolk [2] also recognised the fact that the fissura superior posterior first originates in the hemisphere. The moment, however, at which Bolk believes that the groove arises is undoubtedly too late.

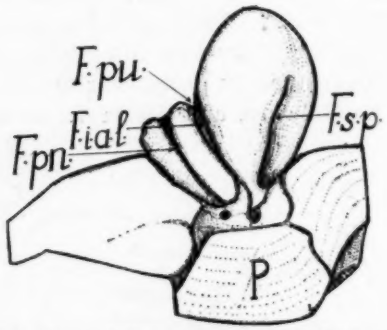

FIG. 9.—Lateral surface of a cerebellum of the end of the third month or of the beginning of the fourth one. Same cerebellum as reproduced in figs. 7 and 8. *F.i.a.l.*, fissura inferior ant., lateral part; *F.pn.*, fissura prenodularis; *F.pu.*, fissura preuvularis; *F.sp.*, fissura superior post.; *P.*, pons. Enlargement × 5.

The cerebellum I described is remarkable in that it shows a stage in which the central region of the vermis is undivided. This fact seems to plead in favour of the view of Schwalbe [16], Bolk [2], and Ziehen [23], who considered this part of the vermis to form an entity. In the hemisphere it is the later lobuli semilunares superior and inferior, and the lobulus biventer that still constitute an undivided mass.

A somewhat older cerebellum of the first half of the fourth month shows clearly the further subdivision of the central region of the vermis. First, a groove appears, which separates the tuber from the rest of the central part (fig. 10). This groove remains strictly confined to the vermis, but in a later stage of development the fissura horizontalis may unite with it. The remaining undivided part is further split up into two lobules by the median division of the fissura superior posterior. This groove is the last furrow of the vermis to appear. The first vestige of this groove arises at a moment when the lateral division of the furrow reaches the sulcus paramedianus and begins to extend into the vermis (fig. 10).

The furrowing of the hemispheres also approaches its completion in this stage of development. The grooves to appear last are the lateral division of the fissura inferior posterior and the fissura horizontalis. The

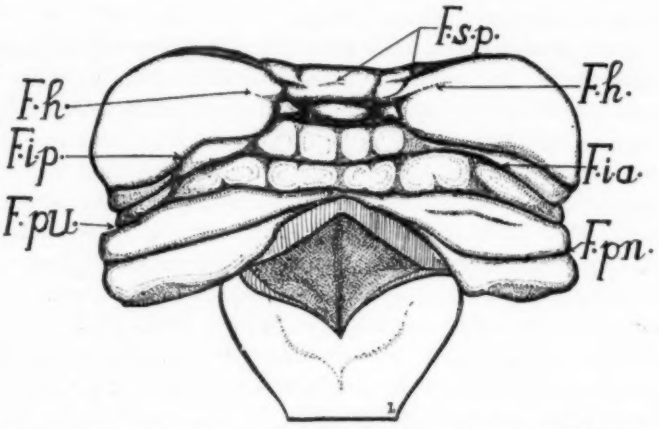

FIG. 10.—Inferior surface of a cerebellum of the first half of the fourth month. *F.h.*, fissura horizontalis; *F.i.a.*, fissura inferior ant.; *F.i.p.*, fissura inferior post.; *F.pn.*, fissura prenodularis; *F.pu.*, fissura preuvularis; *F.s.p.*, fissura superior post. Enlargement × 7.

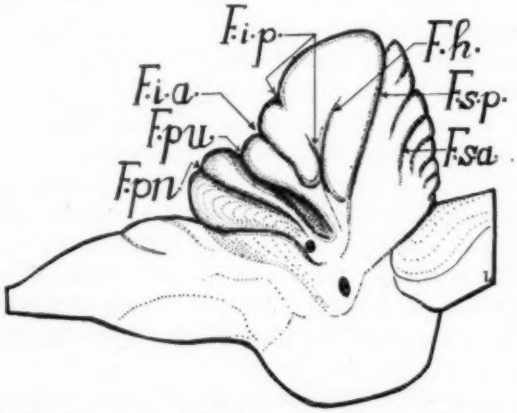

FIG. 11.—Lateral surface of a cerebellum of the first half of the fourth month. Same cerebellum as reproduced in fig. 10. *F.h.*, fissura horizontalis; *F.i.a.*, fissura inferior ant.; *F.i.p.*, fissura inferior post.; *F.pn.*, fissura prenodularis; *F.pu.*, fissura preuvularis; *F.s.a.*, fissura superior ant.; *F.s.p.*, fissura superior post. Enlargement × 7.

former usually precedes the latter. The two grooves originate near the lateral margin of the hemisphere (fig. 11). Very soon after the fissura horizontalis has become visible near the lateral margin, a little

notch appears at the medial side of the hemisphere, which passes into a shallow groove (fig. 10). In the centre of the hemisphere this groove meets that part of the fissura horizontalis which originates near the lateral margin, and unites with it. The fissura horizontalis has, therefore, a double origin in the hemisphere.

The level at which the fissura horizontalis takes its origin on the medial margin of the hemisphere coincides with the groove, which in the vermis separates the folium from the tuber. It is this coincidence which often makes it appear as if the fissura horizontalis were continued into the vermis. That this is not the case and that the fissura horizontalis is merely a hemispherical fissure was recognized by Smith [17, 18]. The view of Bolk that there is some relationship between the fissura horizontalis and the fissura inferior posterior, or that the fissura horizontalis is simply a branch of the fissura inferior posterior, seems to me erroneous. The fissura horizontalis is the last hemispherical fissure of the human cerebellum to appear; its relation to the fissures of the vermis is variable, but it is in man a primary fissure of the hemisphere.

In conclusion, therefore, I find that about the middle of the fourth month the fissure formation of the human cerebellum is completed, and that at this period the grooves of the vermis have united with the grooves of the hemispheres. It is by these grooves that the cerebellum is divided into ten lobes, as enumerated in the table preceding this research. The way in which the cerebellum becomes split up suggests the idea that there is a certain degree of independence of the vermis and of the hemispheres. The formation of fissures, however, takes place according to the same plan and tends to a final state in which vermis and hemispheres appear as parts of an entity of higher order: "the cerebellum." It appears, therefore, likely to me that there may be some truth in the division of the cerebellum by Edinger [7] into a paleo- and a neo-cerebellum. With the details of this division, more particularly with the view that the flocculus appertains to the vermis, I cannot agree.

Before passing on to the description of each of the ten lobes, it is necessary to pay attention to a mode of differentiation of the cerebellar plate, namely, the formation of "foci." A focus is a roundish elevation of the cerebellar surface, of which I do not know at this moment the intimate histological structure. The foci make the impression of being centres of increased growth in the cerebellar surface. The formation of foci is a temporary phenomenon; they first appear at the end of the

third month, in the vermis behind the fissura superior anterior, and also in front of the fissura preuvularis. Shortly after foci become visible in the adjoining parts of the vermis. Later, the foci disappear and up to the end of the fourth month the last traces are visible in the uvula and the pyramis. They persist the longest in the pyramis,[1] where they are also reproduced by Retsius.[2] Each division of the vermis is built up of four foci, two on each side of the middle line (fig. 10). The medial foci very soon coalesce, forming one large focus, so that in this stage of development every division of the vermis is composed of three foci, one median and two lateral ones (fig. 12).

The formation of foci is not obvious in the hemispheres, except in those parts which adjoin the pyramis and the uvula (figs. 8, 10). In the region adjacent to the pyramis, the formation of a focus is a very transient phenomenon, but the focus lying next to the uvula persists for a long while. This focus makes the impression of being a double focus, and later it develops into the tonsilla.

I choose the cerebellum of the first half of the fourth month as a type for the description of the separate lobes, because at that moment the first phase in the development is terminated with the formation of the ten lobes. The second phase is characterized by the transformation of the lobes into the lobules of the cerebellum.

The cerebellum considered as a whole resembles approximately an ellipsoid body. This form results chiefly from the discrepancy in expansion of the surface and of the stalk, with which the cerebellum is connected to the brainstem. The stalk, which is mainly built up by the brachia, as a result of its intimate constitution, remains behind in expansion as compared with the surface. In consequence of the enormous expansion of the surface, the borders of the cerebellum are rolled inwards. The cerebellum resembles, therefore, in many respects an overfilled, closely tied sack. This rolling inwards of its borders proceeds continuously during the whole course of development and reaches its maximum in the adult stage. Though the rolling inwards of the anterior and posterior borders is most marked, it also happens transversely, and this leads to the formation of the fossa transversa. I received the impression that in the majority of cases the left half of the cerebellum precedes in its morphological differentiation the right half, and that also the rolling inwards is most marked on the left.

[1] In the adult form traces of focal differentiation often seem to persist in the lingula. A good specimen of this kind is reproduced by Retsius [14], Table XXXVI, fig. 7.

[2] Retsius [14], Table II, fig. 13, and Table XIV, fig. 2.

The first lobe is the lobus vinculolingualis. This lobe lies entirely concealed in the depth of the fissura precentralis. In an earlier stage (fig. 7) it is still visible from the outside, but by the increasing rolling inwards of the anterior border it disappears in the depth of the precentral groove. There it forms a small white tongue, which rests upon that part of the tectum mesencephali which later becomes the anterior medullary velum. Laterally, the lingula falls away to the bottom of the groove. These lateral portions of the lingula form the vincula, but a distinct limit between these parts is not yet visible.

The lobus centro-alaris is the second lobe of the cerebellum. This lobe is partly overarched by the lobus culminolunatus, in consequence of the rolling inwards of the border of the cerebellum. The anterior

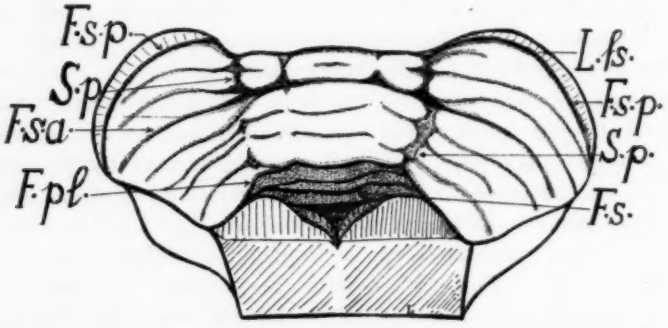

FIG. 12.—Superior surface of a cerebellum of the first half of the fourth month. Same cerebellum as reproduced in figs. 10 and 11. *F.pl.*, fissura prelunata; *F.s.*, fissura secundaria; *F.s.a.*, fissura superior ant.; *F.s.p.*, fissura superior post.; *L.fs.*, lobus foliosemilunaris.; *S.p.*, sulcus paramedianus. Enlargement × 7.

surface of the lobus centro-alaris rests upon the lingula and the tectum, separated from these structures by the fissura precentralis. The posterior surface rests against the lobus culminolunatus, separated from it by the fissura prelunata. In the stage represented by fig. 12 the last traces of focal differentiation still linger. This enables us to state that the lobulus centralis is the vermis portion of the lobus centro-alaris. The sulcus paramedianus is faintly visible only, forming the limit between the lobulus centralis and the alæ. By a deep secondary groove the lobe is divided into an anterior and a posterior section, of which the posterior section is the larger one. This latter lobule is in its turn subdivided by another secondary groove.

The lobus culminolunatus is the third lobe of the cerebellum. The

anterior surface of this lobe rests upon the lobulus centralis and the alæ. With its posterior surface the lobe is turned towards the lobus declivolunatus. Here the fissura superior anterior forms the division between the two lobes. The foci are still perceptible and also the sulcus paramedianus, at least in the left half. On the right, this groove begins to disappear. By the sulci paramediani, the lobe is divided into a vermis portion, the culmen, and two hemispherical parts. In a later stage, when the sulci paramediani have greatly disappeared, the distinction between the vermis and the hemispheres is no longer so evident. Hence, in the adult form this lobe is usually considered to form an entity, the lobulus lunatus anterior (Kölliker). Nevertheless, the discrimination between a vermis portion, the culmen, and a hemispherical section, remains of fundamental interest, independent of the fact that the delimitation between those parts may vanish externally.

If in this stage of development we open the fissura superior anterior, we see at the bottom of this groove lamellæ arising from the posterior surface of the lobus culminolunatus. These lamellæ reach the surface successively, and displace the fissura superior anterior backwards. When this process takes place very actively, it is often difficult, or even impossible, to recognise the original primary fissure. This fact may in a later stage of development cause difficulty in the recognising of the primary fissures, but it is obvious that it does not invalidate the principle of the division of the cerebellum into ten lobes by transversal grooves. The posterior surface of the lobus culminolunatus remains for a long while a centre for the expansion of the cerebellar surface. This process of expansion often proceeds asymmetrically and it also happens that a lamella reaches the surface in the hemisphere, while in the vermis it remains concealed in the depth of the fissure. This is more particularly the case, with the lamellæ to be formed last. In fig. 12 an instance of this kind is reproduced on the right.

The fourth lobe in the series is the lobus declivolunatus. The anterior surface of this lobe rests against the lobus culminolunatus, the posterior surface rests against the lobus foliosemilunaris. From this latter lobe it is separated by the fissura superior posterior. This groove extends into the hemisphere as far as the lateral margin (fig. 11). It is the hemispherical boundary groove between the lobuli lunati, which lie in front, and the lobuli semilunares, which lie behind. The fissura superior anterior, on the contrary, extends only for a short distance into the hemisphere, extending no further laterally than the secondary grooves. The fissura superior anterior may, therefore, be a groove

of fundamental interest in the vermis, dividing an anterior from a posterior section (Bradley [3, 4], Bolk [2]), but in the hemisphere this rôle falls to the fissura superior posterior. This relation also reflects the temporary independence of the vermis and the hemispheres.

The division into vermis and hemispheres by the sulci paramediani is still very definite in the lobus declivolunatus, and whilst the three foci of the vermis are also obvious. A secondary groove, which is not yet completed, divides the lobe into an anterior and a posterior section. This secondary groove appears first in the hemispheres, and a little later in the central focus of the vermis. During the whole course of its development the lobus declivolunatus is the most conservative part of the cerebellum. Consequently, it forms in the adult stage the part with the simplest configuration. Bolk [2] arrived at a similar result from his studies in comparative anatomy, and proposed the name of lobulus simplex. The close relationship, however, between this and the preceding lobe, especially of the hemispherical section, seems to render it desirable to retain the old name of lobulus lunatus posterior. In connection with the statements and the scheme of Bolk, the fact is worth noticing that the lobus declivolunatus shows clearly in this stage of development the distinction between vermis and hemispheres. Hence the view of this author, that the lobulus simplex would be devoid of a vermis portion, is erroneous.

If we consider the superior surface of the cerebellum as a whole, we are struck by the fact that the vermis forms such a considerable part of it. Later, during the further stages of development, the vermis remains behind in its expansion, and the hemispheres become more and more predominant.

The fifth lobe is the lobus foliosemilunaris. This lobe borders from behind on the fissura horizontalis. In the specimen reproduced in figs. 10 and 11, this fissure is not yet completed, but in other objects of approximately the same age the furrow is completed. Hence I cannot agree with Smith [19], who believes that it is not until the end of the fifth or the beginning of the sixth month that the fissura horizontalis makes its appearance.

The vermis part of the fifth lobe, the folium, in this stage of development still forms an element of the external surface. Later, however, it gradually remains behind and is in many cases overgrown by the adjacent parts, and especially by the lamellæ of the tuber. The folium is the last differentiated section of the vermis and, in the adult stage, the most reduced one. It is, like the other sections of the vermis,

originally built up of four foci, but the focal differentiation appears to be transient and to disappear early. Slight displacements may occur in this region between the folium and the adjacent parts of the hemispheres, caused by difference in the rates of expansion of the surface. In consequence of these displacements the endings of the fissura horizontalis and the furrow that separates the folium from the tuber no longer coincide. In this way the different varieties arise, which are met with in the adult in this region. The region of the folium is last differentiated and for this reason it is the most variable part of the human cerebellum.

The hemispherical section of the lobus foliosemilunaris, the lobulus semilunaris superior, is not yet split up by secondary grooves. These grooves appear comparatively late, not before the middle or the end of the fifth month.

The lobus tuberosemilunaris is the sixth lobe. It is separated from the lobus pyramidobiventricus by the fissura inferior posterior. The vermis section of the lobe is subdivided into three parts. The median part, which is by far the largest, takes its origin from the central focus. Later, it develops into the tuber. Both the lateral parts are derived from the lateral foci. These parts remain behind in development, but until the middle of the fourth month they are distinctly separated elements of the vermis. In a later stage, these little fields disappear in the depth of the fissura inferior posterior and there form the small white stalks that unite the tuber with the foremost lamellæ of the lobulus semilunaris inferior. The tuber differs, therefore, in so far from the other lobules of the vermis that it takes its origin only from the central focus.

The two lobuli semilunares give the impression of forming an entity, which is at a comparatively late stage subdivided by the fissura horizontalis. The surface expansion of the lobuli semilunares begins at a very early stage and is most definite in the inferior lobule. In consequence of the considerable development of these lobules, the lateral division of the fissura inferior posterior no longer runs transversally, but bends off a little backwards. In later stages, when the lobuli semilunares prevail still more, the backward inclination of the furrow becomes more accentuated. The excessive expansion of the lobuli semilunares dominates the whole development of the cerebellum, and produces, together with the enormous development of the tonsillæ, the anomalous appearance of the human cerebellum.

The seventh lobe is the lobus pyramidobiventricus. This is

separated from the preceding one by the fissura inferior posterior, and from the lobus uvulatonsillaris by the fissura inferior anterior. The vermis section of this lobe is strongly developed, and still shows in the stage represented in fig. 10 four foci. In another object of approximately the same age the medial foci partly coalesce. The focal differentiation is sharply marked in the pyramis, and it is here that the foci persist longest. The hemispherical part of the lobe, the later lobulus biventer, is narrow, in consequence of the compression exerted by the posterior border of the lobulus semilunaris. Towards the lateral margin of the hemisphere, the lobule grows broader and its surface more convex, so that it appears there as a well-marked part of the lateral surface of the cerebellum (fig. 11).

The hemispherical region immediately adjoining the vermis gives the impression of being differentiated into a focus (fig. 10, on the left). The oblong form of this focus appears to be caused by the compression brought to bear by the posterior border of the lobulus semilunaris, for in an earlier stage this focus is more rounded (fig. 8). In a later stage of development, this focus is overgrown by the adjacent parts of the hemisphere and lies at the bottom of the fissura inferior anterior. There it develops into the white stalk, by which the pyramis is united with the lamellæ of the lobulus biventer. Between the hemispherical focus and the lateral focus of the vermis lies a slightly depressed triangular field, with its base turned towards the fissura inferior anterior. This little field, which is of considerable size when the hemispherical focus is reduced (fig. 10, on right), gives origin, so far as I can see, to the area perforata parapyramidalis of Ziehen [23]. The rest of the hemispherical part of the lobus pyramidobiventricus shows no trace of focal differentiation.

The lobus uvulatonsillaris is the eighth lobe. This lobe is limited by the fissura inferior anterior on one side, and by the fissura preuvularis on the other. This latter groove is a fairly deep furrow, which near the lateral border of the hemisphere grows broad and shallow (fig. 11). In its general features this lobe resembles the preceding one. The vermis part, which still shows four distinct foci, develops into the uvula. The hemispherical part of the lobe is compressed by the lobulus semilunaris, in the same way as the lateral division of the lobus pyramidobiventricus. The region of the hemisphere adjacent to the uvula is focally differentiated. The focus gives the impression of being double; later, it develops into the tonsilla. In the human cerebellum, therefore, the uvula and the tonsilla are originally contiguous parts, belonging to

the same lobe and only separated from each other by the sulcus paramedianus. For this reason I cannot agree with Smith [19], who believes that the connexion between uvula and tonsilla is a secondary one only.

The next lobe, the ninth, is the lobus nodulofloccularis. This is separated from the tenth by the fissura prenodularis. In the stage represented by figs. 10 and 11 it is a well-developed lobe, but very soon it remains behind in development, especially the more medial part of the hemispherical section.

The more lateral part of the hemispherical section differentiates further and gives rise to the flocculus. In consequence of the rolling inwards of the posterior border of the cerebellum, the vermis and the parts adjacent to it are turned towards the fourth ventricle. Hence, the greater part of the nodulus is no longer directly visible. The focal differentiation of the nodulus is only faintly indicated, but the lines of demarcation formed on the sides by the sulci paramediani are clearly defined.

The last lobe is the lobus nodiolovelaris. This lobe had already been recognised by Kölliker [10] as a separate division of the cerebellum, to which he applied the term of "gyrus chorioideus posterior." It is a well-developed lobe, of which the vermis and the adjacent parts of the hemispheres are entirely reversed. From behind, this lobe is continued into the posterior medullary velum. The transition of the velum into the substance of the lobe lies in the central region, not on the posterior border, but a little to the front, so that the nodiolus and the adjoining parts of the hemisphere are covered by the velum.

The nodiolus forms the hindmost section of the nodulus, from which it is separated by the median part of the fissura prenodularis. On the side, the nodiolus is delimited by the sulci paramediani. The wall of the hemispherical section of the lobe atrophies for a great deal in the course of development and is assimilated to the velum. For that reason, I choose the name of lobus nodiolovelaris for this last lobe of the cerebellum.

The next stage is derived from an embryo of the end of the fourth month. At that time the focal differentiation of the superior surface has entirely disappeared and only the last traces of the sulci paramediani are visible (fig 13). The hemispheres have considerably increased their surface and embrace the brainstem. By the change in the form of the superior surface, the course of the fissures is altered. Instead of running transversely they now curve forwards in the hemispheres in agreement with the form of the cerebellum.

The lingula is still small and concealed in the depth of the fissura precentralis. The central lobe forms at this stage the bottom of a niche, enclosed from the side and above by the lobus culminolunatus. This lobe assumes more and more the form of a crescent. By the disappearance of the sulci paramediani, the limit between the vermis and the hemispheres vanishes, and from that moment the lobe gives the impression of being an entity, the lobulus lunatus anterior of descriptive anatomy. In the same way the lobus declivolunatus is transformed into the lobus lunatus posterior. This lobe shows on the right the formation of a secondary groove in the substance of the hemisphere, independent of the existing grooves. At the bottom of this secondary groove lamellæ are formed, which later emerge on the surface.

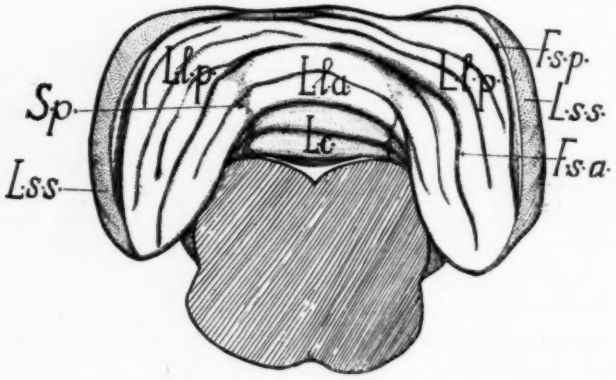

FIG. 13.—Superior surface of a cerebellum of the end of the fourth month. *F.s.a.*, fissura superior ant.; *F.s.p.*, fissura superior post.; *L.c.*, lobulus centralis; *L.l.a.*, lobulus lunatus ant.; *L.l.p.* lobulus lunatus post.; *L.s.s.*, lobulus semilunaris superior; *S.p.*, sulcus paramedianus. Enlargement × 5.

The lobulus lunatus posterior is limited from behind by the fissura superior posterior. This fissure forms a deep groove, which near the lateral margin of the hemisphere flattens and passes over into that part of the fissura precentralis that separates the hemispheres from the brainstem (fig. 15). In this manner a part of the forelip is formed of the fissura transversa.

The inferior surface of the cerebellum seems in many respects more conservative than the superior one. The chief changes are caused by the increase of the lobulus semilunaris. By the great increase in size of this lobe, the lobulus semilunaris superior begins to embrace the

lobulus lunatus posterior from aside (fig. 13). In this way the lobulus semilunaris superior reaches the upper surface, of which it now forms the lateral border. Consequently, the fissura superior posterior is displaced forwards and ceases to be the limit between the superior and the inferior surfaces. This process gradually proceeds in the same direction, until in the course of the sixth month approximately the whole lobulus semilunaris superior forms part of the upper surface. At that moment the fissura horizontalis becomes the limit between the superior and the inferior surfaces of the cerebellum. The displacement of the fissura superior posterior is often overlooked and it was Stroud [22] and Bolk [2] who clearly recognized this fact.

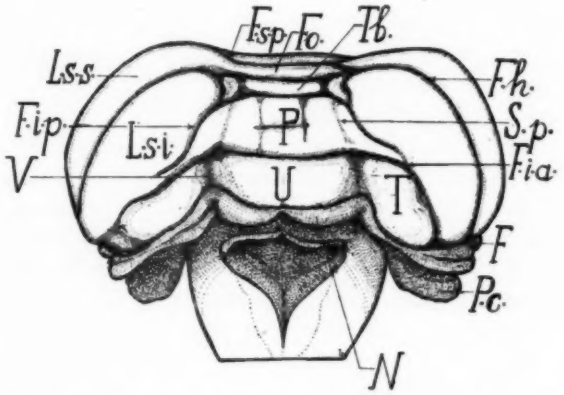

FIG. 14.—Inferior surface of a cerebellum of the end of the fourth month. Same cerebellum as reproduced in fig. 13. *F.*, flocculus; *F.h.*, fissura horizontalis; *F.i.a.*, fissura inferior ant; *F.i.p.*, fissura inferior post.; *Fo.*, folium; *F.s.p.*, fissura superior post.; *L.s.i.*, lobulus semilunaris inferior; *L.s.s.*, lobulus semilunaris superior; *N.*, nodulus; *P.*, pyramis; *P.c.*, plexus chorioideus; *S.p.*, sulcus paramedianus; *T.*, tonsilla; *Tb.*, tuber; *U.*, uvula; *V.*, vallecula. Enlargement × 5.

The lobulus semilunaris inferior still further increases in size and compresses more and more the lateral division of the lobus pyramidobiventricus. The fissura inferior posterior approaches thereby the fissura inferior anterior, while at the same time the more lateral part of the groove becomes flattened and disappears (fig. 14). Finally, in a somewhat older stage than that reproduced in fig. 14, the fissura inferior posterior may unite with the fissura inferior anterior. This state is nearly attained on the right side of fig. 14. By the disappearance of the fissura inferior posterior, the impression is conveyed that the lateral

part of the lobus pyramidobiventricus, i.e., the lobulus biventer, has vanished. Later, however, the fissura inferior posterior reappears (cf. fig. 18). As far as I can see, the disappearance of the more lateral part of the fissura inferior posterior is a normal phenomenon, which always occurs in this stage of development. The union, however, of this fissure with the fissura inferior anterior seems not so constant and in that respect there may even be differences between the right and the left half of the same cerebellum.

The folium, which joins together the two lobuli semilunares superiores, begins to remain behind in its development and in some specimens of approximately the same age it already lies a little below the level of the adjacent parts of the vermis. The tuber, on the contrary, has greatly increased in size, especially in a transverse direction. The small flat fields beside the tuber, which derive from the lateral foci of the vermis, are partly overgrown and begin to disappear from the surface. Later, they form the little white stalks that unite the tuber with the lobuli semilunares inferiores.

In the pyramis the last traces of focal differentiation persist, and this makes it possible to state that the little field, limited laterally by the rest of the fissura inferior posterior, is chiefly composed by the hemispherical focus. The pyramis and the hemispherical foci still lie on the same level, but later the hemispherical foci disappear in the depth of the fissura inferior anterior, where they form the white stalks that unite the pyramis with the lobuli biventeres. In the case of the pyramis it is quite evident that the white stalks derive from the hemispherical foci and one would expect this to be also the case with the stalks uniting tuber and lobulus semilunaris. As far as my material goes, however, the stalks of the tuber seem to proceed from the lateral foci of the vermis.

The lobus uvulatonsillaris is at this stage of development no more a transverse lamella. In consequence of the expansion of the lobulus semilunaris, the tonsilla is displaced and the rest of the hemispherical division of the lobe strongly compressed. The tonsilla now forms an obtuse angle with the uvula and the region between these structures is depressed (fig. 14). This depressed area forms the first origin of the valecula, and because the sulcus paramedianus lies at the bottom of the depression we may say that the valecula arises in the situation of that sulcus. Under the influence of the compression exerted by the lobulus semilunaris inferior, the more lateral part of the hemispherical division of the lobus uvulatonsillaris atrophies, with the exception of a little

well-marked field adjoining the margin of the hemisphere in front of the flocculus (fig. 15). This little field is variable in form and size in different specimens, but it always persists as a distinctly limited and slightly convex area till the sixth or seventh month, or perhaps still longer. This little field, which arises from the most lateral part of the hemispherical division of the lobus uvulatonsillaris, is in my opinion the homologue of the paraflocculus of Smith, the ventral part of the paraflocculus of Bradley and the pars tonsillaris of the formatio vermicularis of Bolk.

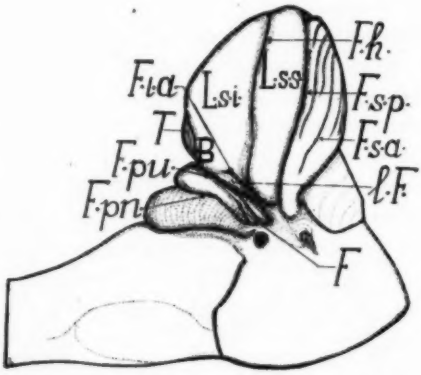

FIG. 15.—Lateral surface of a cerebellum of the end of the fourth month. Same cerebellum as reproduced in figs. 13 and 14. *B.*, lobulus biventer; *F.*, flocculus; *F.h.*, fissura horizontalis; *F.i.a.*, fissura inferior ant.; *F.pn.*, fissura prenodularis; *F.pu.*, fissura preuvularis; *F.s.a.*, fissura superior ant.; *F.s.p.*, fissura superior post.; *l.F.*, lateral field; *L.s.i.*, lobulus semilunaris inferior; *L.s.s.*, lobulus semilunaris superior; *T.*, tonsilla. Enlargement × 5.

The fissura inferior anterior, which forms the front border of the lobus uvulatonsillaris, is in its vermis portion a fairly deep groove. In the hemisphere the groove flattens in the neighbourhood of the lateral pole of the tonsilla. Near the margin of the hemisphere, where it forms the anterior limit of the little lateral field, the groove is again well defined.

The lobus nodulofloccularis has to a great extent disappeared from the surface by the rolling inwards of the posterior border of the cerebellum. Only a small strip is visible, which is partly overarched by the posterior border of the lobus uvulatonsillaris. From this lobe it is separated by the fissura preuvularis. This groove is deep in the vermis, flattens in the hemisphere, in consequence of the incipient atrophy of the wall of the lobe, and again grows deeper near the lateral

margin of the hemisphere; there it borders the flocculus in front. The fissura prenodularis forms the posterior limit of the lobe. This groove is well marked, though not very deep in the hemisphere.

The lobus nodulofloccularis can only be exposed to view by rolling the posterior border of the cerebellum outwards. This I have done in a somewhat older specimen. The embryo from which this cerebellum came was about four months old, or perhaps slightly older. Fig. 16 is the reproduction of the preparation. The vermis part is well developed and laterally bordered by the last traces of the sulci paramediani. The lobe is divided by a secondary groove into an anterior and a posterior division. The first trace of this groove is represented in fig. 10, on the right, and in the stage of fig. 14 the groove approaches its completion. Later, the hemispherical division of the groove disappears in consequence of the atrophy of this part of the lobe.

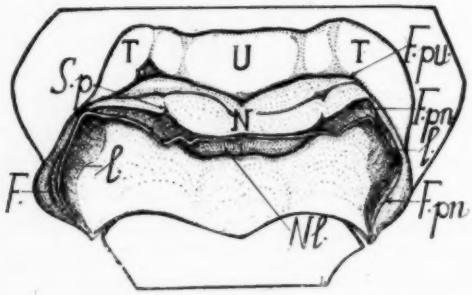

FIG 16.—Posterior border of a cerebellum of an embryo of about four months old. *F.*, flocculus; *F.pn.*, fissura prenodularis; *F.pu.*, fissura preuvularis; *l.*, line along which the medullary velum is torn off; *N.*, nodulus; *N.l.*, nodiolus; *S.p.*, sulcus paramedianus; *T.*, tonsilla; *U.*, uvula. Enlargement × 5.

The most lateral part, however, of the lobus nodulofloccularis does not share the atrophy of the rest of the hemispherical division, but develops into the flocculus. In the stage represented in fig. 11, this part of the lobe is only a narrow band, bordered in front by the shallow extremity of the fissura preuvularis. Gradually this part increases in size and forms a club-like lobule, by which the shallow groove is partly filled up. The continuation of the secondary groove extends into this lobule and divides the head of the club into two parts. Very early a short lamella is formed in the depth of the fissura preuvularis, emanating from the anterior surface of the flocculus. This lamella soon reaches the surface and from that moment the flocculus is composed of three

short lamellæ, which are continued medially into a broad white stalk. This stalk gradually thins off in consequence of the proceeding atrophy of the middle division of the hemispherical part of the lobe. By the atrophy of this part of the lobe, the fissura preuvularis and prenodularis vanish, with the exception of those parts that limit the flocculus. Medially from the flocculus and in the neighbourhood of the lateral pole of the tonsilla, the two grooves often become confluent and may join the fissura inferior anterior, which also begins to flatten in this region. The atrophied part of the lobe is assimilated to the medullary velum and at that moment the stalk of the flocculus seems to arise in the velum. The degree reached by the atrophy of the lobus nodulo-floccularis varies in different specimens, and it is this variability that explains the differences in the form and the relations of the flocculus and its stalk to the surrounding parts in the adult.

The lobus nodiolovelaris increases in size, especially the hemisperical division; this is accompanied by a progressive atrophy of the wall of the lobe, which is gradually transformed into the plexus chorioideus. In the preparation reproduced in fig. 16, I roughly removed the plexus and the atrophied part of the velum. What remains of the lobe is the non-atrophied part. The line along which the plexus and the velum are torn off runs over the external surface of the vermis approaching the fissura prenodularis (fig. 16). In a later stage this line reaches the fissura prenodularis at the lateral border of the vermis, and is there continued along the bottom of the groove. The transition of the cerebellar plate into the velum lies, therefore, in the region of the vermis, not at the posterior margin of the plate, but a little more to the anterior, as already described. Hence the statement of Ziehen [23] that in the adult stage the nodiolus lies intra-velar, covered by the two sheets of the velum, seems erroneous to me, for the velum at the place of transition does not form a duplicature, nor is the velum built up by two distinct sheets.

In the beginning and also during the first half of the fifth month, the further expansion and development of the lobulus semilunaris is the dominating fact. This lobule, considered as a whole, becomes more convex and more distinctly marked off, especially along its lateral border. In the meantime, the lateral division of the fissura inferior posterior reappears. The first trace of the groove emanates from the still existing branch, but very soon the groove arises, also in the middle of the hemisphere, extending towards the lateral border (fig. 17). At the end of the fifth month or the beginning of the sixth, the groove is

completed [figs. 18 and 19]. With the reappearance of the fissure, the lobulus biventer is again split off from the lobulus semilunaris inferior. Hence by the reconstruction of the fissura inferior posterior the original state is restored.

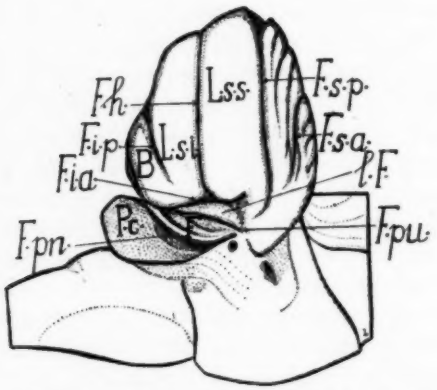

FIG. 17.—Lateral surface of a cerebellum of the first half of the fifth month. *B.*, lobulus biventer; *F.*, flocculus; *F.h.*, fissura horizontalis; *F.i.a.*, fissura inferior ant.; *F.i.p.*, fissura inferior post.; *F.pn.*, fissura prenodularis; *F.pu.*, fissura preuvularis; *F.s.a.*, fissura superior ant.; *F.s.p.*, fissura superior post.; *l.F.*, lateral field; *L.s.i.*, lobulus semilunaris inferior; *L.s.s.*, lobulus semilunaris superior; *P.c.*, plexus chorioideus. Enlargement × 5.

In consequence of the compression exerted by the expanding lobulus semilunaris, the lateral field belonging to the lobulus uvulatonsillaris has lost its connexion with the rest of the lobe. Laterally from the tonsilla, the fissura inferior anterior has joined the fissura preuvularis as represented in fig. 18, on the left. On the right there still exists a small strip uniting the tonsilla with the lateral field. The little field itself may further increase in size, but very soon lags behind and slowly disappears as a separate field.

The atrophy of the lobus nodulofloccularis proceeds further during the first half of the fifth month, and the hindmost lamella of the flocculus shares the regression of the lobe. The two other lamellæ, on the contrary, increase in size, so as to give the impression as if the flocculus were composed by only two lamellæ.

The next stage belongs to an embryo at the end of the fifth month. The changes in the superior surface are not very considerable. This part of the cerebellum continues to develop in the same direction as that already described. The rolling inwards of the anterior border has a

little advanced, and the arching of the middle region, the vermis of descriptive anatomy, is also more evident.

On the inferior surface the regression of the folium and the further development of the tuber and the pyramis are the most striking features (fig. 18). The little fields between the tuber and the lobulus semilunaris inferior have disappeared from the surface. They begin to assume the form of narrow white bridges uniting the tuber with the lobulus semilunaris. The pyramis has strongly increased in size and shows a new set of secondary grooves. In this specimen the last traces of focal differentiation persist in the pyramis, but in most specimens of

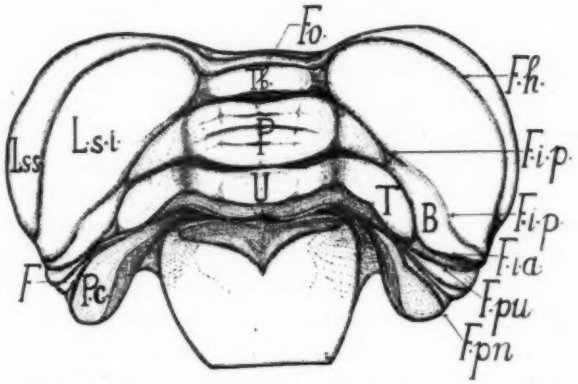

FIG. 18.—Inferior surface of a cerebellum of the end of the fifth month. *B.*, lobulus biventer; *F.*, flocculus; *F.h.*, fissura horizontalis; *F.i.a.*, fissura inferior ant.; *F.i.p.*, fissura inferior post; *Fo.*, folium; *F.pn.*, fissura prenodularis; *F.pu.*, fissura preuvularis; *L.s.i.*, lobulus semilunaris inferior; *L.s.s.*, lobulus semilunaris superior; *P.*, pyramis; *P.c.*, plexus chorioideus; *T.*, tonsilla; *Tb.*, tuber; *U.*, uvula. Enlargement × 5.

the same age the focal differentiation has already entirely disappeared. It seems evident in this specimen that the transverse dimension of the tuber agrees with the dimension of the median focus of the pyramis, so that this also speaks in favour of the view that the tuber is the derivative of the median focus only.

The hemispherical foci of the lobus pyramidobiventricus have developed into well limited triangular fields, which form the union between the pyramis and the lobulus biventer. They still lie on the surface of the cerebellum, but by the formation of the vallecula they disappear from the surface, forming an element of the bottom of this depression. There they persist, even in the adult stage, as the white stalks uniting the pyramis with the lobulus biventer, and as the little

fields described by Ziehen as the "areæ perforatæ para-pyramidales." By the reconstruction of the fissura inferior posterior the lobulus biventer reappears as a separate lobe, which in this specimen extends as far as the lateral border of the hemisphere.

The lobulus uvulatonsillaris has remained behind in its development, in comparison with the preceding lobes. It is only in a later period that the tonsillæ, independently of the uvula, begin to expand and to increase in size. The uvula shows now the first secondary groove, but often this groove is not visible from the outside, in consequence of the rolling inwards of the posterior border. By the same process the lobus nodulofloccularis disappears more and more from the inferior surface. Meantime this lobe partly atrophies, and it is only the nodulus and the two foremost lamellæ of the flocculus that become further differentiated. The wall of the posterior lamella of the flocculus atrophies and the fissura prenodularis, in as far as it limits the flocculus from behind, flattens and vanishes. The atrophy of the lamella and the disappearance of the fissure usually begin at the lateral margin of the hemisphere and proceed medially. By this process the posterior lamella of the flocculus is assimilated to the velum and the fissure that now separates the flocculus from the velum is no longer the lateral extremity of the fissura prenodularis, but the secondary groove, which initially divided the head of the flocculus into two lamellæ. At the same time, however, one or two small lamellæ are formed, emanating from the anterior surface of the flocculus. These lamellæ at the moment of their formation are concealed in the depth of the fissura preuvularis, but later one of these lamellæ may reach the surface.

The lobus nodiolovelaris also atrophies for the greater part, with the exception of those portions which form the nodiolus and the chorioid plexus. The atrophied parts of the lobe are also incorporated in the medullary velum.

In fig. 19 I reproduce the lateral aspect of the same cerebellum from the right side, because it exhibits many peculiarities. It shows the connexion between the uvulatonsilla and the lateral field belonging to this lobe. The lateral field itself is well marked and fairly large. In front this field is limited by a relatively deep groove, the lateral extremity of the fissura inferior anterior. In front of the fissura inferior anterior another groove is visible, which becomes flattened, and seems to end in the neighbourhood of the lateral margin of the hemisphere. This groove is the lateral extremity of the fissura inferior posterior, which borders in front the lobulus biventer. The small strip

of substance between this latter groove and the fissura inferior anterior belongs, therefore, to the lobulus biventer, with which it is still in continuity. This fact proves that by the reappearance of the groove that borders in front the lobulus biventer, the original state is in reality restored. In most cases, however, this lateral part of the fissura inferior posterior does not reappear, and the groove ends at some distance from the lateral border of the hemisphere.

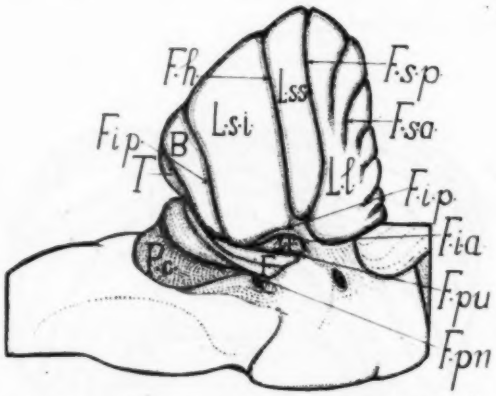

FIG. 19.—Lateral surface of a cerebellum of the end of the fifth month. Same cerebellum as reproduced in fig. 18. *B.*, lobulus biventer; *F.*, flocculus; *F.h.*, fissura horizontalis; *F.i.a.*, fissura inferior ant.; *F.i.p.*, fissura inferior post; *F.pm.*, fissura prenodularis; *F.pu.*, fissura preuvularis; *F.s.a.*, fissura superior ant.; *F.s.p.*, fissura superior post.; *l.F.*, lateral field; *L.l.*, lobulus lunatus; *L.s.i.*, lobulus semilunaris inferior; *L.s.s.*, lobulus semilunaris superior; *P.c.*, plexus chorioideus; *T.*, tonsilla. Enlargement × 5.

In this specimen the fossa transversa makes its appearance as a little depression bordered anteriorly by the lobuli lunati and the lobulus semilunaris superior. The appearance of the fossa transversa indicates the beginning of the third phase in the development of the human cerebellum. It coincides approximately with the end of the fifth or the beginning of the sixth month. The chief characteristic of this third phase resides in the enormous expansion of the hemispheres. The enlargement of the surface, however, is not uniform throughout, but some parts increase, while others decrease or disappear. By this process of local differentiation the cerebellum approaches the adult form.

The expansion of the surface begins near the lateral border of the hemisphere, and is accompanied by a temporary flattening and disappearance of the grooves. There seems to exist a certain antagonism between furrowing and expansion, for, as soon as the expansion becomes

less intense, the grooves reappear. The reconstruction of the furrows occurs, partly autonomously, partly by the outgrowth of the still existing branch of the groove. Most grooves, however, are not completely reconstructed, so that in the adult stage they no longer reach the lateral edge of the hemisphere. In such cases one gets the impression that the hemisphere winds like a gyrus round the end of the sulcus. This fact has probably led Bolk to the conception of a "lobulus ansiformis"; but it is evident that this conception has no fundamental importance, and can only lead to confusion.

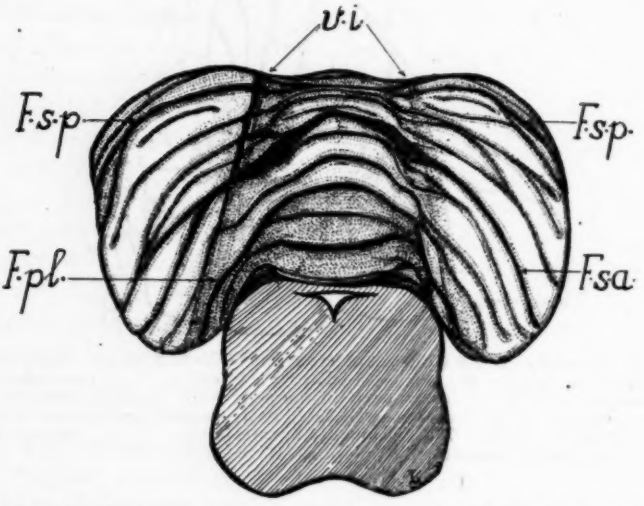

FIG. 20.—Superior surface of a cerebellum of the beginning or of the middle of the sixth month. *F.pl.*, fissura prelunata; *F.s.a.*, fissura superior ant.; *F.s.p.*, fissura superior post.; *v.i.*, vascular impression. Enlargement × 4.

The development of the superior surface of the cerebellum during the last phase is a mere continuation of the processes already mentioned. The vermis becomes more arched, but remains behind in its expansion in comparison with the hemispheres. The hemispheres become, therefore, the predominant parts of the cerebellum. There is no longer a distinct limit between the vermis and the hemispheres. In fig. 20 I reproduce the superior surface of a cerebellum of the beginning, or, perhaps, middle of the sixth month, to illustrate these relations. On both sides of the vermis a longitudinal impression is seen produced by the blood-vessels; but it is obvious that this impression cannot be taken as a limit between vermis and hemispheres.

The lingula at this stage of development has attained its definitive form, the alæ being separated from the middle division by a faint longitudinal groove. This groove is the last remainder of the sulcus paramedianus (fig. 21). The whole formation lies concealed in the depth of the fissura precentralis, covered by the lobulus centralis.

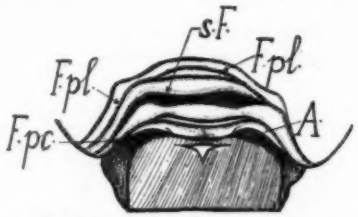

FIG. 21.—Anterior border of a cerebellum of the sixth month. Same cerebellum as reproduced in fig. 20. *A.*, ala lingulæ; *F.pc.*, fissura precentralis; *F.pl.*, fissura prelunata; *s.F.*, deep secondary furrow, dividing the lobulus centralis into two sublobules. Enlargement × 5.

The lobulus centralis is divided by a deep secondary groove into two sublobules. The foremost of the these sublobules has partly disappeared from the surface by the rolling inwards of the anterior border of the cerebellum (fig. 20). The hindmost sublobule, which is the larger one, is still visible, being only partly covered by the lobulus lunatus. Each of the two sublobules is again split up by a secondary groove, so that the whole lobulus centralis is composed of four sublobules. The fissura prelunata, which borders the lobulus centralis from behind, lies in this specimen still entirely in the superior surface, though, on the left, in consequence of the proceeding inward rolling of the anterior border, the furrow begins to disappear from the surface. In other specimina of approximately the same age the rolling inwards of the anterior border has further advanced, so that the lateral division of the fissura prelunata is no more visible. In this respect they more closely resemble the adult form.

A specimen of this kind is reproduced in fig. 22, as seen from the side. The cerebellum belongs to an embryo of the beginning of the sixth month. In this case the lobulus lunatus forms already a niche, in which the lobulus centralis is imbedded. In fig. 23 I reproduce a slightly older stage, in which the development of the lobulus lunatus has further advanced, and in which the covering of the lobulus centralis is more complete. The formation of the niche is the joint result of the

rolling inwards of the anterior border and of the surface expansion of the lobulus lunatus.

The fissura superior anterior, which divides the lobulus lunatus into an anterior and a posterior division, is no longer the leading groove of the superior surface. For the formation of new lamellæ in the depth of the groove is no longer so active, and those that are formed do not reach the surface. In the lobulus lunatus posterior small lamellæ are formed, which unite the existing ones. The grooves, by which these small cross-lamellæ are bordered, form the "sulci pectinati obliqui" of Ziehen [23].

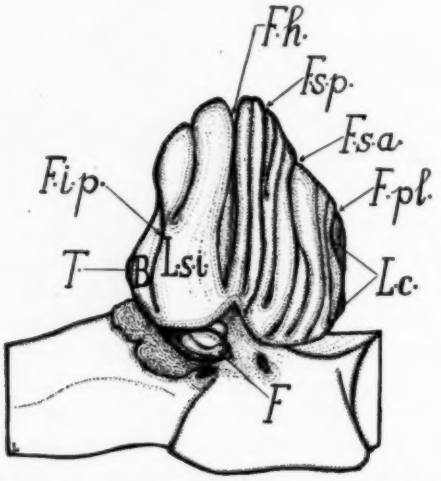

FIG. 22.—Lateral surface of a cerebellum of the beginning of the sixth month. *B*, lobulus biventer; *F*, flocculus; *F.h*, fissura horizontalis; *F.i.p.*, fissura inferior post.; *F.pl.*, fissura prelunata; *F.s.a.*, fissura superior ant.; *F.s.p.*, fissura superior post.; *L.c.*, lobulus centralis; *L.s.i.*, lobulus similunaris inferior; *T.*, tonsilla. Enlargement × 4.

At this stage the fissura superior posterior, which limits the lobulus lunatus from behind, lies entirely in the superior surface. Laterally, where the groove approaches the lateral border of the hemsiphere, it is widened out (fig. 23). At the bottom of this little excavation, a small lamella is formed. This lamella, which first appears in the beginning of the sixth month, is not a constant formation, although I have met with it in the majority of the embryos I have examined (absent in the specimen reproduced in fig. 22). This little lamella develops into a small lobule, situated between the lobulus lunatus and the lobulus

semilunaris, near the lateral border of the hemisphere and often protrudes into the fossa transversa.

From the middle of the sixth month onwards the lobulus semilunaris superior belongs almost entirely to the superior surface. Consequently the fissura horizontalis becomes the limiting groove between the superior and the inferior surface. The differentiation of the lobulus semilunaris superior begins at the end of the fifth month, with the formation of a large secondary groove, originating near the lateral border of the lobule.

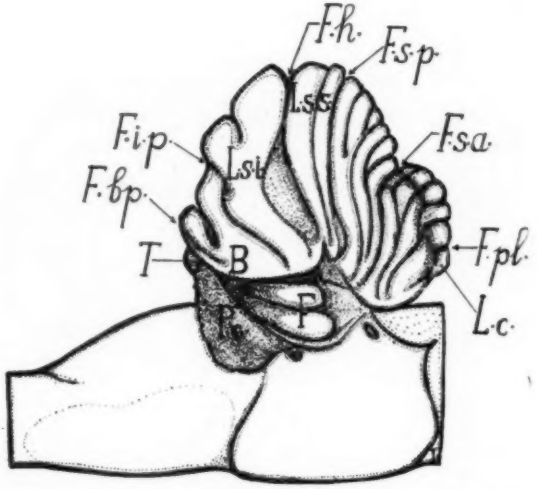

FIG. 23.—Lateral surface of a cerebellum of the beginning or of the middle of the sixth month. Same cerebellum as reproduced in figs. 20 and 21. *B.*, lobulus biventer; *F.*, flocculus; *F.bp.*, fissura bipartiens; *F.h.*, fissura horizontalis; *F.i.p.*, fissura inferior post.; *F.pl.*, fissura prelunata; *F.s.a.*, fissura superior ant.; *F.s.p.*, fissura superior post.; *L.c.*, lobulus centralis; *L.s.i.*, lobulus semilunaris inferior; *L.s.s.*, lobulus semilunaris superior; *P.c.*, plexus chorioideus; *T.*, tonsilla. Enlargement × 4.

In the course of the sixth month this groove extends medially but remains strictly confined to the hemisphere. In the adult this secondary furrow can easily be recognized, because it divides the lobulus semilunaris superior into an anterior and a posterior division (figs. 22 and 23).

The lobulus semilunaris inferior also increases in size, especially along its lateral border. At the end of the fifth month, the first secondary groove appears, soon followed by two other grooves on either side of the first one, so that at the beginning of the sixth month the lobule is subdivided into four parts by three secondary

grooves (fig. 24). The grooves take their origin in the median margin of the lobule and extend laterally. Shortly after, new secondary grooves arise in a somewhat irregular way, whereby the four sublobules are further split up (figs. 24 and 25, on the left).

The tuber which forms the union between the two lobuli semilunares inferiores lags somewhat behind in its expansion in comparison with the lateral lobules, and thereby gradually loses its connexion with the hindmost sublobules of the lobulus semilunaris. These hindmost sublobules which have lost their connexion with the tuber are often described as forming part of a separate lobe, the "lobulus gracilis."

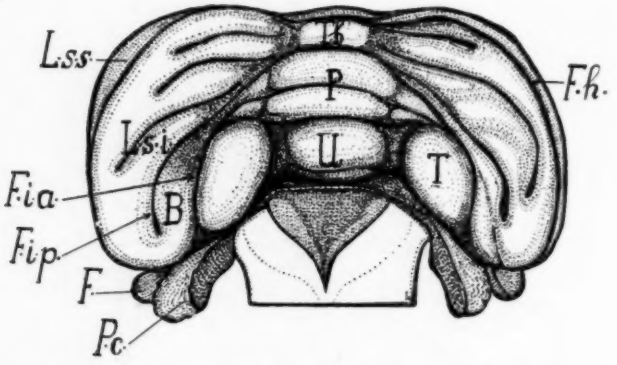

FIG. 24.—Inferior surface of a cerebellum of the beginning of the sixth month. Same cerebellum as reproduced in fig. 22. *B.*, lobulus biventer; *F.*, flocculus; *F.h.*, fissura horizontalis; *F.i.a.*, fissura inferior ant.; *F.i.p.*, fissura inferior post.; *L.s.i.*, lobulus similunaris inferior; *L.s.s.*, lobulus similunaris superior; *P.*, pyramis; *P.c.*, plexus chorioideus; *T.*, tonsilla; *Tb.*, tuber; *U.*, uvula. Enlargement × 4.

The mode of reconstruction and the final course of the fissura inferior posterior may show many variations. In the more simple cases, the lateral division of the groove forms the direct continuation of the medial divisions (fig. 24 on the left and fig. 25 on both sides). In other cases, the groove approaches the fissura inferior anterior in the neighbourhood of the top of the tonsilla, unites with the latter for a short distance and then reappears as a separate groove (fig. 24, on the right).

In the first case we find a lobulus biventer in direct connexion with the pyramis; in the second, the connexion is not manifest, and, if existing at all, the uniting bridge between pyramis and lobulus biventer lies concealed in the depth of the fissura inferior anterior.

The pyramis itself is divided by a deep secondary groove into

two sublobules (fig. 24). This secondary groove also extends laterally into the lobulus biventer, subdividing this lobule into an anterior and a posterior division. On its way laterally, the groove often touches the tonsilla, joining over a short distance the fissura inferior anterior, and then reappears as a separate groove (fig. 25). The anterior division of the lobulus biventer, which is by far the smaller one, is often described as forming part of the lobulus gracilis. The conception, however, of a lobulus gracilis, composed of elements belonging to two different cerebellar lobes, seems to me erroneous. I should rather

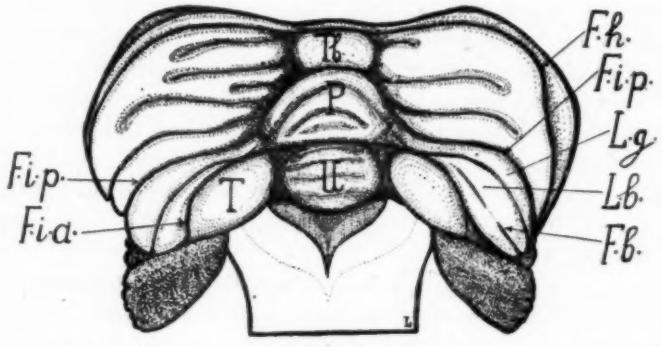

FIG. 25.—Inferior surface of a cerebellum of the beginning or of the middle of the sixth month. Same cerebellum as reproduced in figs. 20, 21, and 23. *F.b.*, fissura bipartiens; *F.h.*, fissura horizontalis; *F.i.a.*, fissura inferior ant.; *F.i.p.*, fissura inferior post.; *L.b.*, lobulus biventer, *s.s.*; *L.g.*, lobulus gracilis; *P.*, pyramis; *T.*, tonsilla; *Tb.*, tuber; *U.*, uvula. Enlargement × 4.

be inclined to propose the denomination "lobulus gracilis" for the anterior divisions of the lobulus biventer, and "lobulus biventer sensu strictiori" or briefly, "lobulus biventer" for the posterior divisions of the lobe. In the adult form, however, it is often difficult, or even impossible, to recognise the fissura inferior posterior, and in those cases the true limit between the lobulus gracilis and the lobulus semilunaris inferior cannot be assigned. The posterior division of the lobulus biventer, or the lobulus biventer s.s., is split up by a secondary groove, emanating from the lateral border of the lobule. This secondary groove, which may always be recognized in the adult stage, is described by Ziehen as the "sulcus bipartiens" (fig. 25, on the right).

The fissura inferior anterior, which separates the lobus pyramido-biventricus from the lobus uvulatonsillaris, flattens in the neighbourhood

of the lateral pole of the tonsilla and vanishes. The disappearance of the groove is caused by the atrophy of the more lateral part of the lobus uvulatonsillaris. At first this part of the lobe narrows and forms a small bridge joining the tonsilla to the little lateral field. Gradually the small bridge and the little lateral field flatten and disappear. At the same time the tonsilla, and especially its lateral pole, becomes more prominent and sharply marked off.

The position of the tonsilla is also altered. The longer axis of the tonsilla, which at first runs transversely, approaches more and more an antero-posterior direction. From within the sulcus paramedianus, the valecula has originated, and into this the tonsilla is pressed down by the expanding lobuli semilunares and biventer. The tonsilla, in this stage of development, shows no trace of secondary grooves, and it is only two or three weeks later that the first secondary groove appears, by which the tonsilla is divided into two sublobules (fig. 28, on the left).

The uvula is subdivided by a secondary groove into two lobules (fig. 24). This groove is situated near the posterior border of the uvula and is soon followed by other secondary grooves in a somewhat irregular way (fig. 25).

The fissura preuvularis, which forms the limit between the lobi uvulatonsillaris and nodulofloccularis, approaches more and more the posterior margin of the inferior surface. In consequence of the atrophy of the greater part of the lobulus floccularis, the fissura preuvularis further flattens and disappears, so that this groove runs out in the neighbourhood of the lateral pole of the tonsilla. The extreme lateral part of the groove persists, and forms the anterior limit of the flocculus.

The lobulus nodulofloccularis can only be exposed to view by rolling outwards the posterior border of the cerebellum. In fig. 26 I reproduce such a preparation pertaining to an embryo of the beginning or of the middle of the sixth month. The nodulus is still connected with the flocculi by means of elongated triangular stalks. Vestiges of these stalks may persist in the adult state, forming the white brachium noduli. The nodulus is divided by two secondary grooves into three sublobules These grooves remain limited to the nodulus and do not extend into the stalks. The flocculus consists in this stage of development of only two sublobules, which begin to show the first traces of a further subdivision by grooves emanating from the lateral margin. On the left of fig. 26, the accessory flocculus is exposed to view by turning the flocculus a little aside.

The lobus nodulofloccularis is bordered from behind by the fissura

prenodularis. The hemispherical part of this groove flattens more and more in the course of the sixth or seventh month in consequence of the atrophy of the corresponding part of the lobe. The atrophied part of the lobe is assimilated to the posterior medullary velum, and it is therefore from that moment on that the nodulus and the flocculus are united by the velum.

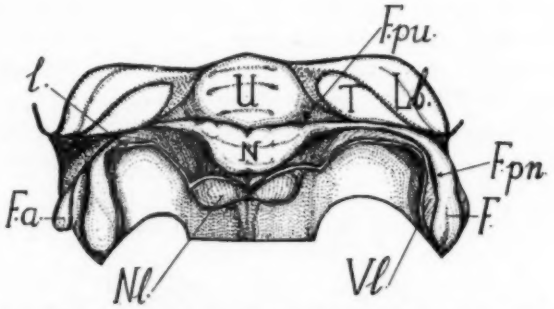

FIG. 26.—Posterior border of a cerebellum of the beginning or of the middle of the sixth month. Same cerebellum as reproduced in figs. 20, 21, 23, and 25. *F.*, flocculus; *F.a.*, flocculus accessorius; *F.pn.*, fissura prenodularis; *F.pu.*, fissura preuvularis; *l*, line along which the medullary velum is torn off; *L.b.*, lobulus biventer; *N.*, nodulus; *Nl.*, nodiolus; *T.*, tonsilla; *U.*, uvula; *Vl.*, velum medullare post. Enlargement × 4.

The hemispherical division of the last lobe, the lobulus nodiolovelaris, is entirely atrophied, and only the vermis portion persists. This part forms what I have termed the nodiolus. The nodiolus is separated from the nodulus by the middle divisions of the fissura prenodularis. The atrophied part of the lobus nodiolovelaris is incorporated in the velum and partly transformed into the chorioid plexus. In the preparation reproduced in fig. 26 the plexus and the more atrophied parts of the velum have been removed. The line along which these parts are torn off still runs across the nodiolus. This relation is only intelligible if we remember that the transition of the cerebellar plate into the velum did not lie at the posterior margin of the plate, but a little anteriorly. In a later stage of development and also in the adult state, the transition of the velum into the cerebellum lies more in front, at the bottom of the fissura prenodularis (fig. 29). In that case the whole nodiolus protrudes freely into the ventricular cavity covered from the outside by the velum.

The nodiolus is still undivided, but in a somewhat older stage this structure is also split up by secondary grooves. In the same way as the nodulus, the nodiolus is laterally prolonged into two stalks, the brachia

nodioli. These brachia form part of the velum, of which they represent a less atrophied part. The brachia nodioli sometimes persist in the adult state as small white tracts, running parallel to the brachia noduli. In fig. 27, I represent the nodiolus and its brachia from behind and also the connexion between velum and brachia by means of a frenulum.

In the course of the sixth month the fossa transversa is completed by the formation of the hindmost lip (figs. 22 and 23). This lip is chiefly formed by the lateral margin of the lobuli semilunaris inferior and biventer. Initially, the fossa transversa is a broad triangular depression, but by the expansion of the hemispheres the two lips approach each other, whilst the fossa narrows and becomes deeper. The top of the groove lies a little anteriorly in respect of the lateral extremity of the fissura horizontalis, and in most cases this relation is the persisting one.

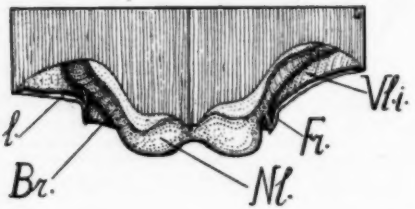

FIG. 27.—Posterior border of a cerebellum of the beginning or of the middle of the sixth month. Ventricular aspect. Same cerebellum as reproduced in figs. 20, 21, 23, 25, and 26. *Br.*, brachium nodioli: *Fr.*, frenulum; *l*, line along which the medullary velum is torn off. *Nl.*, nodiolus; *Vl.i.*, velum medullare post., ventricular surface. Enlargement × 4.

I end my description of the development of the external form with a cerebellum belonging to an embryo of the last half of the eighth month or perhaps slightly older.

The superior surface differs but little from the description already given. The number of lamellæ has increased by the formation of tertiary grooves, but the general feature of the surface has not changed. This is also the case with the inferior surface. This surface, by the increasing size of the hemispheres, approaches more and more the adult form. The folium has disappeared from the surface and in fig. 28 the connexion of the folium with the lobulus semilunaris lies concealed at the bottom of the fissura horizontalis.

The external surface of the tuber is subdivided into three lobules, which are connected with the three foremost sublobules of the lobulus semilunaris inferior. The posterior sublobules are for the greater part

connected by means of white stalks with those lamellæ of the tuber which lie concealed in the depth of the fissura inferior posterior.

The pyramis is subdivided by a deep groove into two subdivisions. On the left, the anterior sublobule of the pyramis is in direct connexion with the anterior sublobule of the lobulus biventer (lobulus gracilis). On the right, this connexion is not manifest, and here it is the anterior part of the lobulus biventer s.s. which is connected with the foremost sublobule of the pyramis.

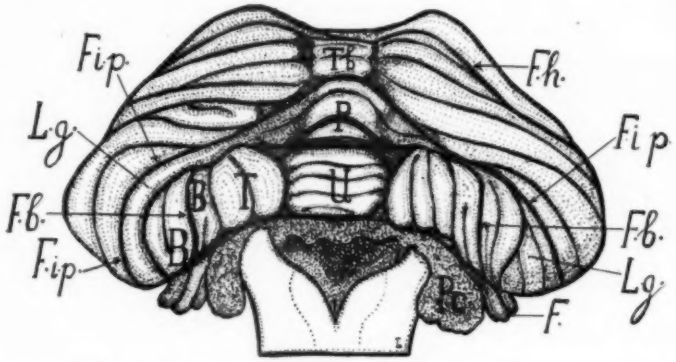

FIG. 28.—Inferior surface of a cerebellum of the last half of the eighth month. *B, B*, lobulus biventer, *s.s.*; *F.*, flocculus; *F.b.*, fissura bipartiens; *F.h.*, fissura horizontalis; *F.i.p.*, fissura inferior post.; *L.g.*, lobulus gracilis; *P.*, pyramis; *P.c.*, plexus chorioideus; *T.*, tonsilla; *Tb.*, tuber; *U.*, uvula. Enlargement × 3.

The uvula becomes gradually triangular, being compressed laterally by the tonsillæ. Meanwhile, the valecula broadens and deepens, forming the niche in which the tonsillæ are embedded. In this specimen the left tonsilla is divided into two sublobules by a secondary groove, which becomes later the fossa axialis of Ziehen [23].

In consequence of the increased rolling inwards of the posterior border, the lobulus noduloflocculari s can only be exposed to view by cutting away the tonsillæ and the brainstem. Fig. 29 is the reproduction of the preparation after removal of the more atrophied parts of the velum and the chorioid plexus. Because the velum has only partly followed the rolling inwards of the posterior border of the cerebellum, this structure is reversed along the posterior margin of the flocculus. The line, along which the velum and the plexus are torn off, disappears at the lateral border of the nodulus in the depth of the fissura prenodularis, so that the nodiolus as a whole is covered by the velum. The

nodiolus itself is rolled inwards and for that reason not visible in fig. 29. The brachia nodioli are atrophying, but still perceptible as white prominences on the inner surface of the velum. In this relation as well we approach the adult form.

It seems evident from the description I have given here that the planning of a satisfactory scheme of the human cerebellum meets with many difficulties. The insurmountable obstacle lies in the fact that the cerebellum is neither a developable surface nor a surface that can be easily projected upon a plane. Every scheme of the human cerebellum is, therefore, not a schematic representation of the true form, but a

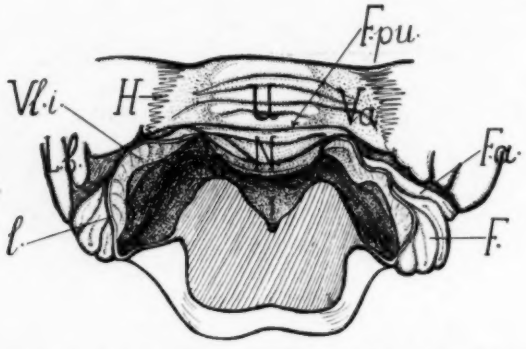

FIG. 29.—Posterior border of a cerebellum of the last half of the eighth month. Same cerebellum as reproduced in fig. 28. *F.*, flocculus; *F.a.*, flocculus accessorius; *F.pu.*, fissura preuvularis; *H.*, hilus tonsillæ; *l*, line along which the medullary velum is torn off; *L.b.*, lobulus biventer; *N.*, nodulus; *U.*, uvula; *Va.*, vallecula; *Vl.i.*, velum medullare post., ventricular surface. Enlargement × 3.

condensed graphic interpretation of facts which have only a remote relation to the observed form. Moreover, the scheme, which represents the cerebellum at the end of the first phase of its development, will be different from the scheme representing the cerebellum at the end of the second or of the third phase.

The scheme of Edinger [7] has the merit that it recognizes the vermis as a separate part of the cerebellum. The union, however, of the vermis with the flocculus into a new entity, the palæocerebellum, is not confirmed by my researches. This conception rests chiefly upon the fact that there are cases of unilateral affections of the nuclei pontis or of the middle peduncle, in which the vermis is intact and the hemisphere atrophied, with the exception of the flocculus.[1] This fact

[1] Brouwer [6] has given a description of such a specimen and also the literature on the subject. A little later Strong [21] published another case of this kind.

proves, however, not the intimate relation between vermis and flocculus but only that the chief connexions of the flocculus are not with the pons.[1]

Another merit of the scheme of Edinger is that it admits of a transverse subdivision of the cerebellum into lobes and that every lobe consists of an associated vermis and hemispherical division. The division by Edinger of the cerebellum into three principal lobes seems arbitrary, but nevertheless there exists some resemblance between the cerebellum at the end of the third month (figs. 7 and 8) and the scheme of Edinger.

The scheme of Bradley [3, 4] is not so simple as that of Edinger. He also recognizes the division of the cerebellum by purely transverse grooves, but in his scheme the vermis does not form a well-defined separate part. The division of the cerebellum into lobules resembles closely the division of the cerebellum of the first half of the fourth month (figs. 10 and 12), but the combination of these lobules into the five lobi A, B, C, D and E does not seem to be well founded. Especially the creation of a lobus C, composed by the lobi declivolunatus, foliosemilunaris and tuberosemilunaris, as well as the conception of a lobus D built up by the lobi pyramidobiventricus and uvulatonsillaris, does not seem in harmony with the facts observed in the human cerebellum.

In the scheme of Smith [17, 18], the fact seems incorporated that for a short time the furrowing of the vermis and of the hemispheres occurs independently, especially in the central zone of the cerebellum. Another merit of this scheme is the creation of a large area ptereoidea and post-ptereoidea. In these features the scheme of Smith would probably agree with a stage of development intermediate between the stages represented in figs. 8 and 10. Smith disregards, however, the fact that even in the central zone of the cerebellum the fissures of the vermis and of the hemispheres finally meet, forming complete transverse fissures.[2] Consequently, the Smith scheme has the disadvantage of not recognizing that the whole cerebellum, and not only his lobus anterior, is built up by transverse lamellæ. On this account the scheme is not fully applicable to the case of the human cerebellum.

More complicated and still less applicable to human relations is the scheme of Bolk [2]. In many respects this scheme resembles that of Smith. His conception of a lobulus ansiformis, and especially of a

[1] Experiments of Bárány [1] and others prove that the flocculus is in close connexion with the vestibular system.

[2] With the exception in some cases of the fissura horizontalis.

formatio vermicularis, as morphological entities, is not to be reconciled with the primary division of the human cerebellum by complete transverse fissures into ten separate lobes. Hence it seems impossible to recommend the application of the nomenclature of Bolk to the human cerebellum.

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